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Electricity Simplified

The Practice and Theory of Electricity

INCLUDING
A POPULAR REVIEW OF THE THEORY OF ELECTRICITY,
WITH ANALOGIES AND EXAMPLES OF ITS PRACTICAL
APPLICATIONS IN EVERYDAY LIFE. WITH AN APPENDIX CONTAINING THE LATEST DISCOVERIES
IN ELECTRICAL THEORY, ALSO EXPLANATIONS OF THE X-RAYS, WIRELESS TELEGRAPHY, MULTIPLE UNIT, ELECTRIC
TRACTION, ETC., ETC.

BY
T. O'CONOR SLOANE, A.M., E.M., Ph.D.
AUTHOR OF
Standard Electrical Dictionary, Arithmetic of Electricity,
Electric Toy Making, Etc., Etc.

Twelfth Edition, Revised and Enlarged

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PREFACE.

It is a fair presumption that the modern developments in the electric field, as generally understood, have occurred within the lifetime of the readers of this work. The achievements of engineers have preceded theory, and to-day the latter is far in arrears, and seems likely to stay so. It is a peculiarity of mankind that it is most strenuous in seeking an explanation of the strange and unfamiliar. We are willing to spend a life, dependent in every physical sense upon gravitation, without once seeking its cause. But for electricity, in its aspect of a new and strange creation of man's ingenuity, though in no way a greater mystery than gravitation, an explanation is required.

To play a part in gratifying this desire is the object of the present work. A theory, which is far from complete has been constructed by modern scientists, and may eventually acquire perfect shape. The hypothetical luminiferous ether is at its base. The probable identity of species of electromagnetic and light and heat waves give us an additional right to use the ether in explaining these manifestations of electricity. This theory is treated here.

It is the fashion to consider the ether a thing of proved existence, and to treat its properties as quite within human conception. Neither practice is correct. The existence of the ether has not been absolutely proved. Its properties are such as to remove it beyond the powers of conception of most or all of us. Edgar A. Poe's limitation of human intelligence applies well here. He says: "I doubt, indeed, whether the man lives who can force into his brain the most remote conception of the interval between one milestone and its next neighbor upon the turnpike."

The practical aspect has been kept in view. The use of analogies and the portions devoted to the engineering world will, it is hoped, prevent the reader from feeling that the work is purely on theory. Its object is to unite theory and practice. If this has been done, its mission is complete.

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ELECTRICITY SIMPLIFIED.

CHAPTER I.

THE ETHER—ELECTRICITY—FORCE AND ENERGY—MASS AND WEIGHT.

The Ether—Electricity.

THERE are in nature certain mysteries, if such a name does not appear too poetical, which have never been solved and may remain so for all future generations. The conservative scientist is apt to include among such things gravitation, electricity, and perhaps light. To explain the phenomena of light, an almost inconceivable entity termed the luminiferous ether has had to be invented. By assuming such a thing to exist and to be endowed with almost inconceivable properties, light is explained and its phenomena are brought into the domain of mathematics. But no direct proof of the existence of the ether has yet been found, and we hardly can venture to hope for one.

The modern treatment of electricity deals with it as representing and including special phenomena of this ether. Some go so far as provisionally to define it as being the ether itself, and to treat static excitement, magnetism, current electricity, etc., as due entirely to different states of the ether.

The luminiferous ether is by calculation deduced as being of the following general properties. It is supposed to be a medium most resembling a gas in constitution, yet possessing rigidity like a solid, as well as elasticity like that of a gas. Its density is equal to 936 one-thousand-million-millionths ($\frac{936}{1000000000}$) that of water, or equal to that of air at 210 miles above the earth. Its rigidity is one one-thousand-millionth ($\frac{1}{1000000000}$) that of steel. It is sometimes compared to an all-pervading jelly, through which waves of light and other radiant energy and of electromagnetism are constantly throbbing. Particles of ordinary matter move through it without resistance. It interpenetrates the molecules of matter, and hence an air pump is entirely without effect upon it. There is no such thing as an ether vacuum (Daniel). It cannot be excluded from empty space.

Such is the hypothetical luminiferous ether, an ultra-gaseous body possessing the properties of both a solid and of a gas. It should be looked upon as an expedient for the present, as something most useful in formulating theories, but unproved. A theory is often little more than a symmetrical skeleton to sustain our laboriously acquired collection of facts. The test of the utility or perfection of a theory is its ability to foretell what will happen under given conditions. It may be able to do this and yet be wholly fictitious.

Light is radiated from one body to another across enormous intervals of space. The mind cannot conceive of one body acting upon another without some connecting medium. The same applies to gravitation and electricity. The ether originally invented to account for the transmission of light through distances, of unknown degrees of immensity in the case of the heavenly bodies, has been found a useful factor in formulating a theory of electricity.

If any object is excited electrically, every object within its range of action, that is to say, which is not screened from its effects, is also affected. This involves the same kind of action across a space as obtains in the case of light. It is termed radiant action and is a manifestation of radiant energy. Again, an electric current or the poles of a magnet produce magnetic effects in their vicinity upon objects not in contact with them. This involves action at a distance also.

These are among the reasons which have induced scientists to invoke the luminiferous ether to aid in explaining and accounting for electrical phenomena. As employed in the present work it will be found useful in enabling the mind to better formulate a theory of the science. Extraordinary as the idea of the ether may appear, it is evident that the modern achievements of electricity are just as strange. They are of such nature as to be entitled to an extraordinary line of explanation.

The sun is at such a distance from the earth that it takes light over eight minutes to travel from its surface hither. The nearest of the fixed stars are so remote that in many cases days and years are consumed in the passage of light from them to us. If one of these bodies were suddenly annihilated we should see its light after it ceased to exist. The sun would seem to continue to shine for eight minutes and twenty seconds after its extinction. We may even now seem to see stars which long ago ceased to be luminous, and distant suns may now be radiating light into space, which light will not reach us to show us a new star, for years to come.

All this is so strange and deals with such infinite relations of quantities as regards distances and time that the luminiferous ether, viewed from such a standpoint, seems not too extravagant a conception to account for the high velocity and intensity of radiant energy.

Pulses or waves of electric energy are found to act like light, to be capable of transmission through some bodies, of reflection from others, and of refraction and interference. The relations between electrostatic and electromagnetic units indicates a ratio corresponding to the velocity of light. These considerations give direct ground for utilizing the theoretical ether as a medium for the propagation of electrical disturbances.

The term radiant energy is continually acquiring new scope in physics. Many phases of electrical disturbance fall under this heading. Others may be attributed to radiant force.

The passion for unification at one time tended to obliterate the old distinction between static and dynamic electricity. Now a true basis for such division must be recognized and may to a certain extent be determined by the consideration of force and energy. True static phenomena are phenomena of ether stress or of force; electromagnetic wave and current phenomena are related to ether waves or energy.

Force, Energy, Mass, and Weight.

Physical concepts, such as force, mass, energy, and other elementary things, have received within recent years much accuracy and definition of description and attributes. Only a few years ago great confusion existed, notably in the distinction between force and energy. The enunciation of the absurd doctrine of the conservation of force, and its support in many essays and papers by those who were assumed to be the leading thinkers of the day, is an illustration, now but a few years old, of this fact.

This accuracy has led, and is leading, to more and more subdivisions, which brings about a multiplication of units, and increase in nomenclature especially in electricity, which has already been felt to be a misfortune, although it is not easy to see how it is to be avoided.

For the purposes of this work it is quite unnecessary to enter into all of these subdivisions. There are a few elementary mechanical ideas which may be enunciated before the electrical part is entered on. These involve subjects which are often sources of error and misunderstanding.

As physics and mechanics are based upon measurement, units of different kinds have been established. They are based upon length, time, and weight. The relations of these factors to the compound units are termed the dimensions of the unit. The centimetre, gram, and second are the bases of measurement, and the fundamental units constructed or built up upon them are termed the centimetre-gram-second or C. G. S. units.

FORCE is that which, acting on a quantity of matter or mass, can change its rate of motion or can impart motion to it. It can be called into existence or annihilated under adequate conditions; in other words, there is no conservation of force. Its unit is that force which can in one second impart to one gram of matter a velocity of one centimetre per second. This unit is termed the *dyne*. The weight of one gram is equal to about 981 dynes. A dyne is equal to about 63½ grains.

The exertion of force along a path in space, which condition necessarily implies motion against resistance, is termed WORK. Its unit is a dyne exerted through a path one centimetre long. The most convenient way to express force is to refer it to gravitation. Hence the unit of work is generally defined as the raising of $\frac{1}{981}$ gram to a height of one centimeter against gravitation. The name of the unit is the *erg*.

The power of doing work is termed ENERGY. A weight of $\frac{1}{981}$ gram by frictionless machinery could, in descending one centimeter, raise another body of the same weight the same distance. Hence it would be said to possess energy of position, a form of potential energy, equal to one erg. The sum of energy in the universe is invariable; energy can be neither created nor annihilated by natural causes. This is the doctrine of the conservation of energy, which has replaced the discarded one of the conservation of force.

If a bullet is fired from a gun, the energy of the combustion of the powder is in part expended in driving the bullet forward ; in part in driving the gun backward, producing recoil; in part in heating the gun and bullet, and in various other ways. None of its energy is destroyed. The bullet strikes a target and is brought to rest. Its energy is not destroyed, it is only transformed. Some appears as heat energy—indeed most of it directly or indirectly takes this form; none disappears.

If this doctrine is true, perpetual motion against resistance, as generally understood, is impossible. There is very little doubt of this doctrine's truth.

It follows from the above that energy cannot, properly speaking, be expended, and that work is not done at the expense of energy. Work simply denotes the reciprocal of a given form of energy, and is produced by the disappearance of that particular form of energy, and is the result of its conversion into some other form. A weight raised by the combustion of coal is the reciprocal of the heat energy, and no more represents work than it does the product or the result of the conversion of heat energy into mechanical potential energy. In other words, work and energy may be treated as identical. To do work, energy is required, and is absorbed in the process by being converted into some other form or forms. The other forms, either one or more of them, are in many cases some irreclaimable form or forms, which can never again be utilized. This is so often the case that the available energy of the universe is undoubtedly tending to zero. This zero will be attained when all objects have the same temperature.

A body placed at a height above a plane possesses what is termed potential energy, referred to the plane. Its advantageous position indicates a power of doing work. Another example of potential energy would be a strained spring, possessing the energy of stress.

A body in motion, by virtue of its inertia or resistance to reduction of velocity, can do work, and is said to possess kinetic energy. A body at rest in a certain sense may be said to possess the same with reference to moving bodies, because all rest and motion are relative.

An example of the transformation of energy can be taken from the above. A one-pound weight raised one hundred feet has expended upon it one hundred foot-pounds of energy, and possesses that amount of potential energy. If now it is allowed to fall through the same distance, it parts with its potential and assumes kinetic energy. When it has fallen one hundred feet, if in a vacuum, it will at the one-hundred foot mark possess none of its original potential energy, but in its place will have one hundred foot-pounds of kinetic energy. As it strikes the ground and comes to rest, this energy will change into heat energy and other forms, but it will remain the same in amount—one hundred foot-pounds.

MASS is the quantity of any portion of matter. Owing to centrifugal force a body weighs less at the equator than at the North Pole; upon the surface of the moon it would weigh far less. Yet its mass would be the same although its weight might vary. Were transportation cheap enough, and were the other conditions favorable, a merchant could make money by selling by weight, in northern or southern latitudes, goods which he had purchased by weight in equatorial latitudes, provided he weighed with a spring-balance. He would buy and sell the same weight, but would buy a greater mass than he sold.

WEIGHT is mass acted on by gravity. As gravity varies, weight will vary, even though the mass remains the same: all which has been just illustrated.

In electricity we have force and energy. Heat energy in driving an engine that drives a dynamo becomes ultimately converted into electric energy. An electric machine or a battery on open circuit maintains its terminals at a varying potential, or in such state as to exercise electromotive force. This force, producing a current through a resistance, does work. As for electric mass and weight, as yet they are not recognizable, and probably do not exist.

CHAPTER II.

THE ELECTRIC CHARGE—POTENTIAL—THE DIELECTRIC—POSITIVE AND NEGATIVE ELECTRICITY—CONTACT ACTION—ELECTROSTATIC LINES OF FORCE—THE LEYDEN JAR.

The Electric Charge, Potential, and Dielectric.

THE first idea of electricity is that we are able to place bodies in different electrical relations. A stick of sealing-wax or the amber mouthpiece of a pipe rubbed upon the coat sleeve will attract bits of paper, or will draw around with it, magnet-like, a walking-stick suspended by a thread tied around its centre. The very name electricity is derived from the Greek name for amber.

The sealing-wax or amber in the above case is said to be charged with electricity, and represents the form of electric force already spoken of. It is useless to attempt to determine what the electricity is whose presence so alters the condition of the body. It is usually taken as an entity of some kind, and in old times was termed and now is often termed colloquially a fluid, although it is certain that it is no such thing.

A body electrically charged is most simply treated as one whose surface is surcharged or undercharged with electricity. By an electric machine based upon contact action, by a galvanic battery, or by other means, electricity can be altered in its distribution. The action is analogous to that of a pump which pumps water from one reservoir into another, both originally of equal level. Thus we may imagine two reservoirs of similar level of water. If water is pumped out of one and into the other, they are brought into such relation that, if any chance was given, the water would flow from one to another, and the original level would be reached again. If for these reservoirs we substitute bodies insulated from any supply of electricity, we can by an electric generator, which we may term an electric pump, abstract electricity from one and add it to the other. Both bodies are then said to be charged, one positively, the other negatively. As in the case of the reservoirs of water, if any chance was given, electricity would flow from one to the other, and the original state of things would be re-established.

The electric charge resides entirely upon the surface; the cubic contents of the body has nothing to do with it. Again as regards a specific surface, there is no limit to the electricity which can be charged upon it, provided it can, so to say, be held there. By a physical metaphor, the elasticity of electricity seems to be perfect and indefinite.

This gives the idea of an electric charge. Returning to our reservoirs of uneven level or "charged," if they were connected the original level would be attained, and more quickly or slowly in proportion to their difference of level. The greater this difference, the greater will be the tendency to return to the original level. The same applies to the electric charge. The greater the difference of charge, the greater will be the tendency toward partial equalization. This difference of charge is termed difference of potential, or potential difference, or electromotive force, and the terms high or low potential in a system indicate a large or small difference of charge of different parts.

The levels of water in the reservoirs, instead of being compared with each other, might be referred to that of an ocean of constant level. Water might be pumped from one into the ocean, or from the ocean into one or the other, or both, so as to affect their level, with respect to such an ocean of constant height. Electricity can be treated in like manner. It can be pumped from the ocean of electricity, which the earth represents, or the same earth can be used as a recipient of charges pumped from other bodies. Any of our reservoirs put into communication with the ocean would at once begin to attain the same level. Any charged electrical body put into communication with the earth, will in a short time, which may be an infinitesimal fraction of a second, be reduced to the standard potential of the earth, which by convention has been taken as zero potential, just as in stating elevations of the earth's surface the height of the water of the sea is made the basis or zero of height.

The fact that, other things being equal, the capacity of a body for holding a charge of electricity depends upon the area of its surface is shown in a familiar experiment. If a piece of tinfoil or other conducting material is charged, and is then rolled up, thus reducing its area, the charge shows a higher tension or desire to escape. It is to a certain extent as if the area of one of our reservoirs was in some way diminished. The water would rise in height and acquire a greater pressure. This experiment also proves very clearly the fact that an electric charge resides upon the surface.

Small drops of water charged with electricity, if they unite to form larger ones, will present a smaller total surface, and hence will raise the potential of their charge. This is supposed to be one of the causes of the electric disturbances in thunder showers, where the electric charge of the atmosphere seems to increase in potential enormously.

The reservoirs, if to be filled or partly emptied, must have walls of some strength. If of the level of the ocean, their walls may be of zero strength for they will be supported outside by the ocean water which we may assume to penetrate the soil. To enable the surface of objects to hold an electric charge, they must be surrounded by something to retain it. This substance or entity that holds a charge, upon a surface, which substance or entity represents the walls of the reservoirs, is termed the dielectric. It may be the air or any of the non-conductors of electricity. Even a vacuum is a dielectric almost equal to air. This fact is generally expressed by stating that the ether is a dielectric.

If connected by a pipe, the reservoirs will discharge one into the other and assume the same level. If two electrically charged bodies are connected by a piece of metal such as a wire, they will at once assume the same potential. The wire is termed a conductor. All metals and many other substances conduct electricity so well as to be termed conductors. Others conduct it so badly as to be termed insulators. The latter are all capable of acting as dielectrics.

If the air was a conductor, a surface could never be excited or charged in it, there could be no thunder storms, and man would probably have never known anything about electricity unless from animal sources such as the torpedo and gymnotus. Water containing salt in solution is a conductor. Hence there are no electric storms or disturbances in the ocean and its inhabitants only experience animal electricity, but never that from any other source.

The dielectric is the opposite of a conductor. Anything that is not a conductor may act as a dielectric.

Formerly no distinction was drawn between it and an insulator. Now any insulator that surrounds a charged body, whether that insulator be glass, India rubber, gutta-percha, air, or a vacuum, is called a dielectric.

As the charge is to be held upon a surface, and not within a body, it is evident that for quick charging the surface must be conducting. Sealing-wax, amber, and glass, for instance, are non-conducting, and receive a charge only with difficulty, and part with it also with difficulty. If coated with tinfoil, gold-leaf, or some thin metallic coating, they become much easier to charge, although their capacity remains unchanged.

This question of capacity is affected by two things, the area of the surface and the nature of the dielectric. The capacity of a system of two conductors and an intervening dielectric, called a condenser, is the quantity of electricity it can retain at a given potential. A typical form consists of two pieces of tinfoil with a sheet of gutta-percha, mica, or paper dipped in paraffin, between them. It is charged by passing or introducing opposite kinds of electricity into the two sheets of foil. As this is done the potential difference between the tinfoil layers rises, more rapidly as the surfaces are smaller, and this potential rise varies also very curiously with the nature of the dielectric. This difference between dielectrics depends on specific inductive capacity.

Positive and Negative Electricity.

A zero of potential being accepted, arbitrarily taken as that of the earth, it is found that bodies can be excited so as to bear opposite relations not only to each other but also to the earth. This at once establishes the idea of positive and negative electrical excitation, and of positive and negative charges. It is found that if a piece of glass is rubbed against a piece of amber they will become oppositely excited. As a matter of convention, the glassy or vitreous electricity is called positive, and the resinous electricity is called negative.

One body cannot be charged with a quantity of positive electricity without an equal charge of negative electricity being established somewhere else, and *vice versa.* The algebraic sum of equal positive and negative quantities being zero, the sum of all electrical charges in the universe is zero. This doctrine is comparable to the law of the conservation of energy, in the sense that the sum is constant, and it has been termed the law of the conservation of electricity.

If copper and zinc are brought into contact and are separated, the copper is charged with negative, the zinc with positive, electricity.

If the copper and zinc be immersed in acid which acts most strongly upon the zinc, the distribution is different: the zinc is negatively, the copper is positively, charged. This is the case in a galvanic battery.

This question of positive and negative gives the convention for fixing the direction of a current. A current is assumed to be the discharge of positive upon negative. If negative electricity is poured into a body it adapts that body to receive a positive charge of equal value.

All this is conventional; it is merely a necessity of the case. Some assumed direction of current and nomenclature of excitation is required.

It will be observed that the relative conditions of zinc and copper are opposite when immersed in acid or when separated from contact. This is because when immersed in acid the excitation or charge is derived from the separation of the constituents of the water in which the acid is present. The hydrogen with its positive charge travels to the copper; the other constituent atom of the water, or radical of the acid molecule, it may be, travels with its negative charge to the zinc. This negative charge it pours into it, or rather discharges it upon its surface, thereby adapting it to receive an opposite and equal charge of positive electricity from the copper.

According to Franklin's views, who treated electricity as a single fluid, the positive charge consists in an excess and the negative charge in a deficiency of electricity. Hence in the above illustration the zinc becoming negatively charged merely means that it loses a part of its total quantity of electricity. This carries out the idea of the direction of a current.

The overflowing or positively charged body, namely the copper, sends a current, if permitted, into the partly exhausted or negatively charged body.

Therefore, according to the single-fluid theory, a charge indicates an excess or deficiency according as it is positive or negative. It carries out well the theory of the conservation of electricity.

The double-fluid theory assumed that there were two fluids, one positive and one negative, neutralizing each other in equal quantities.

Now both these theories are discarded almost entirely. It is convenient as an analogy, however, to treat of electricity as a fluid in some of its manifestations, and simplicity will be gained and the truth more nearly approximated to by using the single-fluid hypothesis where it gives a useful analogy.

The charge, positive or negative, is really the keynote of all electrical phenomena. All that we know of electricity are the manifestations due to charges held upon surfaces and intermittently discharged, which is static electricity; or to charges continuously supplied and discharged along conductors, which is kinetic or dynamic electricity. The methods of producing these charges are by contact action and induction. To the first may be referred so-called frictional machines and also batteries.

The relations of bodies oppositely charged in general are that the opposite electricities tend to combine. Bodies oppositely charged, therefore, attract each other. Under certain conditions they can impart their opposite charges to each other and then are no longer attracted.

The bodies excited oppositely as described and attracted cannot impart their charges one to the other through space, except where a conductor connects them, or, if not, where the charges are of high enough potential difference in relation to the space separating them and to the substance filling it. In that case they may discharge by a violent action producing a spark and noise. This disruptive discharge is seen in the lightning stroke.

If the excited bodies are brought into contact, they will adhere, because the opposite electricities tend to combine. This adhesion, when satisfied, represents the disappearance of a specific form of energy. As energy cannot be annihilated, this specific form must be converted into some other, which other form is heat energy. The heat of combination of dissimilar metals, or of other substances, usually in the order of chemical energy and affinity, is also in the order of electrical energy. This correlates chemistry and electricity.

If, instead of bringing the bodies in contact with each other, they are connected by a metallic rod, their relative excitement disappears as long as they are thus connected. The rod acts to provide a path for the electricity and, as we have seen, is called a conductor. The electricity passing by the path thus opened for it is termed a current. If one of the bodies is drawn away from the conductor, it has a charge proportioned to the difference of electrical character between itself and the conductor.

Just as the like poles of magnets repel each other, so two bodies excited with like qualities of electricity repel each other.

If an excited body, for instance one with a positive charge, is brought near an indifferent or uncharged body, it attracts it. This it does by attracting to the part of such body nearest it the opposite or negative electricity. This it attracts by attracting the body itself. If negatively excited, it also attracts by drawing the positive electricity of the body toward itself, and hence drawing the body as before.

Contact Action and Electrostatic Lines of Force.

Imagine two bodies of identical substance placed near together. A slight attraction will be exerted by each upon the other, which is termed the attraction of gravitation. Touch and separate them and the attraction will remain the same, and will vary, if they are small enough, in a certain proportion to their distance apart; if of small enough relative dimensions, with the square of such distance. Next assume two bodies of dissimilar nature placed near together. They will be attracted by mutual gravitation. Now touch them, best by rubbing to secure good contact, and separate them, and they will exhibit a strong attraction for each other. Under ordinary conditions this attraction will be vastly more than that of gravitation. A piece of sealing-wax rubbed against the coat sleeve will attract the sleeve. The contact acts to establish bonds of attraction that operate like India-rubber bands, pulling the two objects together. The objects are then said to be electrically excited. In this excitement and attraction not only the bodies but the intervening ether is thought to be concerned. The ether is supposed to be so stressed as to represent or act like connecting India-rubber bands, and to pull the bodies together. The same applies to a magnet and its armature. The magnet throws the ether into an analogous state of stress. As its armature is brought near it, this stress is affected by its proximity, and acts to draw magnet and armature together. As the stress is easiest pictured as connecting lines, and as these lines indicate the exercise of force, they are termed lines of force, the first electrostatic lines, the others electromagnetic lines.

There is no good analogy by which these phenomena can be pictured. Sometimes attempts in this direction are made by picturing the ether as composed of intermeshing cog-wheels. By using this conception, various states of stress can be figured, but the examples do not seem very practical.

The action of lines of force between excited disks or other objects is shown in the following illustrations. When objects electrically excited with opposite electrical conditions are brought near together, the lines of force run almost straight from one to the other of the facing areas, while other lines curve around from the backs and sides of the objects. As they are more separated, the lines curve outward, always tending to separate from each other, until the conception of what occurs is what is illustrated in the second cut.

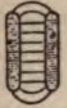

FIG. 1.—ELECTROSTATIC LINES OF FORCE BETWEEN NEAR SURFACES.

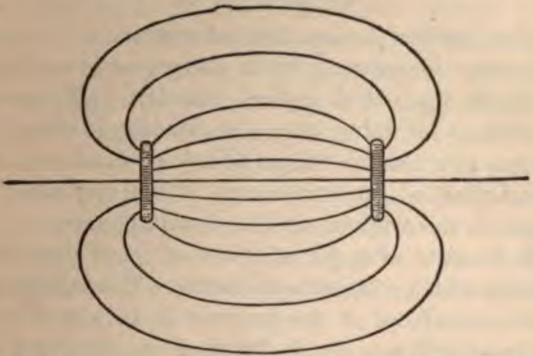

FIG. 2.—ELECTROSTATIC LINES OF FORCE BETWEEN DISTANT SURFACES.

The expression "lines of force" must be regarded as purely a matter of convenience. There are no real lines any more than there are individual and distinct rays of light.

This attraction of electrified bodies has been noticed for many centuries. The first observed electrical experiment on record is the attraction of rubbed amber for pieces of chaff.

Unsatisfactory as these statements appear in the light of explanation, they are as satisfactory as any explanation of gravitation that can be evolved. But we are so familiar with gravitation that we do not stop to think about it, or to assign a cause for it.

The Leyden Jar.

The Leyden jar is a form of condenser. It is an apparatus for storing up a charge, or actually two equal and opposed charges of electricity. To provide conditions for doing this, a conducting surface is required, to which should be added a second such surface, to hold an opposed charge of contrary name and to retain the original one as a bound charge.

It consists of a jar of glass of good insulating quality, which acts as the dielectric. The interior and exterior surfaces of the jar over its bottom and half or two-thirds way up to its edge are lined with tinfoil pasted on. The foil provides the conducting surfaces to rapidly receive, hold, and rapidly discharge the charges. The glass above the foil is best shellacked or coated with sealing-wax varnish, to prevent condensation of moisture. Such moisture would act as a conductor, and would provide an electrical connection between the two surfaces of tinfoil. A rod extends through the cork and connects with the inner coating.

To charge the jar from a single source of electricity of high potential one coating is put into communication with the source in question, and the other is connected to the earth.

Electricity at once flows from the source to the surface connected to it, while the similar electricity is expelled from the other coating into the earth. Thus, as far as the earth is concerned, there might as well be no Leyden jar in the path of the current. As much electricity as flows into one coating is expelled, being the same quantity of the same name, from the other coating into the earth. The jar itself does nothing to disturb the balance.

The process of charging goes on until the potential difference of the two coats may be very high. On removing the jar, it is charged. One coating holds positive, and the other negative, electricity; both charges are bound to each other, and are exactly equal in amount. On touching or nearly touching both surfaces at once with the ends of a wire or other conductor, a spark will spring across and the surfaces will be nearly discharged. After a few minutes a second slight discharge (of the residual charge) can be taken from it.

The Leyden jar, which in a certain sense bottles up electricity, originated in an accident. An old-time experimenter, it is said, once approached or touched the prime conductor of an electrical machine with a nail protruding from the neck of a bottle containing water. The moisture on the outside of the bottle, it must be presumed, acted as an outer coating, and the water provided the same for the interior. On removing his bottle he received from it a violent shock. He had succeeded in putting electricity into a bottle.

By arranging Leyden jars in different ways, the discharge can be made to vary in relations of quantity and intensity as in the case of a galvanic battery.

If the jars are arranged with all the outside and all the inside coatings in communication, a large quantity of electricity can be accumulated. By arranging them in series, the inside coating of one in communication with the outside coating of the next, and so on down the series, they will accumulate but a small charge proportional to the surface of a single jar, but of higher potential according to the number of jars in series.

The difference of potential regulates or determines the length of spark which can be produced from given electrodes. When discharging a jar by interposing a conductor between the opposed coatings, the discharge always takes place before absolute contact, a spark appearing in the interval. By the length of this interval the length of the spark and with it a general idea of the tension is defined.

The old frictional electric machine operates with the earth as a basis and charges the surface of its metallic prime conductor. Its general operation is exceedingly simple. A circular plate or a cylinder of glass is turned by hand. A cushion or pair of cushions are arranged in contact with the plate, so as to rub against it when rotated. These cushions are in communication by a metallic chain or otherwise with the earth. The contact brought about by friction and the constant separation of the glass surface from the cushions charges the glass with vitreous or positive, and the cushions with resinous or negative electricity. The prime conductor which is provided with a row or two rows of teeth, like a saw, nearly touching the glass as far from the cushions as possible, partly neutralizes the excited glass by communicating to it a charge of negative electricity, thus remaining positively excited. Meanwhile the earth is absorbing the excess of negative electricity from the cushions as fast as it is produced by the rotating plate.

If the reader will examine any of the old type of frictional machines he will readily follow out the above.

The machine therefore establishes a charge in the prime condenser which, as its bound charge, has the excess in the earth. This sensitiveness of the earth to minute charges, strongly evidenced in the ground circuit of telegraph and telephone systems, is very surprising. The great sphere seems as sensitive to the smallest excess as to the greatest.

Thus a person standing on the ground receives a spark from the prime conductor of a machine that has been worked. This indicates the rejoining of the excess of positive electricity on the surface of the prime conductor with the excess of negative electricity on the earth's surface.

The application of this to the Leyden jar is interesting. In charging a jar its inner coating generally is brought in contact with the prime conductor, and its outer coating communicates with the earth through the person holding it.

The prime conductor communicates its charge to one coating, as just said, generally in practice the inner. The same quantity of the same kind of electricity is expelled by induction from the other coating of the jar, going to the surface of the earth. Thus the earth returns to neutrality as far as the excitement of the particular machine in question is concerned. The inner and outer coatings of the jar become oppositely excited, coming into the same relations as those originally existing between the prime conductor and the earth.

Thus the two bound charges are separated only by thin glass, whereas when the prime conductor held a charge it was bound by the earth's charge.

The full discussion of the Leyden jar involves very complicated calculations; and what has been said only gives a very general idea of its operation. It is interesting to note its action in the charging process, when it conveys a charge to the earth by induction, although the jar has an insulating wall of glass between its conductors.

From the principles involved it follows that a Leyden jar placed upon an insulator cannot be charged.

There is a way in which a jar can be charged without the intermediation of the earth. The coatings may be connected, each one to oppositely excited conductors. Each one is then charged from its respective conductor.

This system is followed in influence machines and may be used with induction coils.

CHAPTER III.

THE ELECTRIC CURRENT AND CIRCUIT—RELATIONS OF ELECTROMOTIVE FORCE, RESISTANCE, AND CURRENT—VELOCITY OF ELECTRICITY.

The Electric Current and Circuit.

WHEN a body is charged with electricity we have seen that it indicates an equal and opposite charge somewhere else. The influence of an electrified body is to a certain extent like that of gravity—it may extend everywhere through space. Just as a man theoretically cannot leap from the earth without pushing the earth away from himself an infinitesimal distance, so an electrified body may determine more or less stress in the most distant regions.

If now a conductor is stretched from a region of one charge to a corresponding region of another opposite charge, it separates or makes a tunnel in the dielectric, and the ether stress is relieved along the line of the conductor. The opposite electricities at once begin to neutralize each other by flowing along the path opened by the wire.

What part the wire and ether relatively play in the transmission of the electricity is still a matter of discussion. In all practical calculations and work the wire is assumed to be a direct conductor and the only thing concerned in the conduction. The passage of the charges, if continuous, is called a current. Such passage to be continuous demands a constant supply of electricity, such as afforded by a battery, or a dynamo, or a constantly working electric machine.

The easiest and simplest analogy for a current is the flow of water. If we return to the reservoirs used as an illustration in preceding pages of this work, we find there the analogy of a current which equalizes two opposite charges. But it is obvious that to maintain a current from one reservoir to the other there must be some return path. This brings us to the conception of an electric circuit. Our water circuit must include what is virtually a return path, and so must an electric circuit. In some sense it must represent a complete cycle.

A very familiar type of a circuit is given by a battery whose ends are connected by a wire. The current goes through the wire and, electrolytically, through the fluid of the battery. If the continuity is broken anywhere, there will be no current. When the circuit is complete, a current passes. The continuous and complete one is called a closed circuit; the discontinuous one is called an open circuit. The opening of a switch or release of a wire from a binding screw is enough to convert one into the other.

If, in the hydraulic analogy the reservoirs be dispensed with, and a centrifugal pump in action be taken to represent a battery or dynamo, then a pipe connecting its inlet and outlet will represent a wire carrying a current. The system is complete in itself. If a hole were made in the pipe the water would not rush out, as the whole is self-contained. This is the case with a complete electric circuit.

It is obvious that the pump might be kept in action by pumping from an ocean and back into the same ocean without disturbing its level. This would represent what is known as a ground circuit.

It was an early discovery in the telegraphic world that a complete metallic circuit was not necessary, but that in common parlance the earth could be used as a return circuit. This type of circuit is represented by a battery with a wire leading from one pole to any desired point, and then to the earth. From the other pole a second wire leads to the earth. It is immaterial on what part of the line the battery is placed.

In this case the earth acts exactly like a conductor, with one difference: it has no resistance.

No one can assert that the current in such a case really goes through the earth. One end of the line pours electricity of one kind into the earth. A corresponding and exactly equal quantity escapes from the earth at the end of the other conductor, and goes to the battery. It is simply the case of the pump and the ocean over again. The earth acts as a great reservoir, and not as a conductor. Hence it is without resistance, just as the ocean would not have the resistance of a pipe.

The action is the same as in the case of a frictional electric machine just described. A centrifugal pump has been taken as the representative of an electric generator. Such a pump is peculiar in one respect as compared with piston pumps: if its inlet or outlet is closed, it does no work except such as is due to friction. To make such a pump run easily, the stopcock of the pipe leading from it should be closed. Then, were it not for friction, it would run on forever with but little absorption of energy, and would maintain a difference of pressure. Incidentally it may be noted that the closing of a stopcock consists in placing across the path of the water a substance through which it cannot pass, namely, a solid metal. The water current is surrounded by material of the same class, namely, the metal composing the walls of the pipe through which it flows.

The battery or other electric generator operates in the same way. If its inlet or outlet conductor is closed by a substance through which the current cannot pass, it will, except for wasteful action, friction, etc., maintain a difference of potential without absorbing energy or doing work. The closing and impassable substance may be any dielectric. Invariably in practice it is air. A switch is simply opened, which amounts to inserting a mass of air in the path of the current. The same dielectric in many cases surrounding the wire, as in telegraph lines, defines the path of the current, as the metal walls of a pipe define the path of a water current. Air in such a case represents to a certain extent the lead, iron, or brass of the water pipe, and represents exactly the metal of the plug of the water valve.

The conductor of an electric current, though conveniently pictured as a pipe, differs probably in its action therefrom. The ether surrounding it is supposed to be an active agent in maintaining the current; and the wire or conductor, while it carries the current also, enables the ether to do the work of pushing the current on its way. Thus some imagine a current not as determined by end action through a wire, but by a series of pushes or impulses communicated through the ether outside the conductor, and localized by it all along its own line.

Relations of Electromotive Force, Resistance, and Current.

The cause of a current being the uniting of two charges opposite in quality, it is defined as due to a difference of potential. If such is maintained between two points connected by a wire or other conductor which forms a path for a current, it obviously represents a kind of current-producing force, one which can keep electricity in motion against resistance. It is for this reason also termed electromotive force, which for shortness is often written E.M.F.

Electromotive force is the force maintaining or capable of maintaining a current through a conductor. There is no perfect conductor known. Just as there is no frictionless conduit for water, so there is none for electricity. Force therefore is exacted in causing a current to flow through any path opened for it. The cause for this exertion of force is called resistance.

In the case of currents the action of resistance is very simple. It restrains the intensity or strength of a current due to a given electromotive force, causing more or less to flow through a circuit in simple proportion to the resistance itself. The three factors, current, electromotive force, and resistance, are evidently interdependent. Their relations to each other are stated in the well-known Ohm's law thus: The current is equal to the electromotive force, divided by the resistance. This famous law is at the base of a large proportion of electrical calculations, and its applications are developed in treatises on the subject of the mathematics of the science.

While resistance thus affects the quantity of electricity which flows under the action of a given electromotive force through a conductor, it is without effect or action upon the velocity of transmission of an electric impulse. The facts that copper wire possesses less resistance than iron wire and also transmits signals quicker have no inter-relation with each other. A small copper wire transmits telegraph signals more rapidly than a large one, the latter of course being of much less resistance.

If we take a wire through which a current is passing, and examine its electrical condition, we shall find it a seat of electrical and thermal disturbances. It is a seat of energy, and as energy is expended on it it becomes heated. If by proper instruments we examine the relative potentials of its different parts, we shall find a difference of potential existing between different places upon it, the differences of potential all falling in the one direction. This change of potential as it is expended in forcing a current through a wire is termed the fall or drop of potential. If the conductor is of uniform resistance, the fall of potential in any given portion will be in proportion to the length of such part of the wire.

An excellent mechanical representation of the fall of potential is given by a wire subjected to twisting or torsion. The illustration shows an apparatus for carrying out this representation of an electric circuit. The vertical wire is supposed to represent a portion of a conductor. The twist which is given it represents the electromotive force, and its degree is read off by the hands upon the dials. The weight which is sustained, by the lever at the bottom being turned slightly with the twist of the wire, represents the current intensity. If the wire is more twisted, it can support a greater weight. The twisting is taken to represent electromotive force or difference of potential, the increase of which factor maintains a greater current through a conductor or wire, which increased current is represented by the heavier weight.

On the wire the intermediate hands assume positions dependent on the amount of twist given the upper hand, and proportional exactly to their distance from it. This illustrates the law of the fall of potential. In a conductor carrying a current the fall of potential in any given part is proportional to the resistance of such part. Therefore if the conductor is of even section and resistance throughout, the fall of potential will be proportional to the length of any given portion.

The decrease or fall of potential along an active circuit tends also to eliminate the idea of a current being due to a simple end push. The electromotive force is present everywhere in a circuit. The current is due to a determinable electromotive force in every active circuit, and fractional parts of the cir-

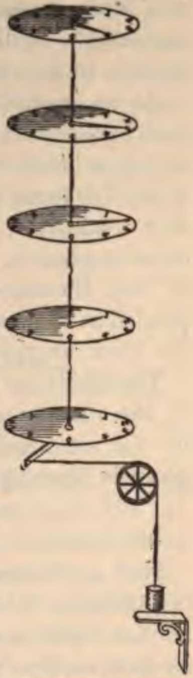

FIG. 3.—MECHANICAL ILLUSTRATION OF FALL OF POTENTIAL AND CURRENT STRENGTH.

cuit are actuated by fractional parts of the electromotive force. The portion of this total electromotive force expended in forcing the current through any section or division of the circuit is in exact proportion to the relative resistance of such section.

As an example, a battery of ten units' resistance may be assumed as supplying an outer circuit of ten units' resistance also. Then one-half of the electromotive force will be expended in overcoming battery resistance, and one-half in overcoming the outer resistance. If the same battery supplies a line of one thousand units' resistance, the energy expended in the outer circuit is equal to nearly $\frac{99}{100}$ of the total energy.

The efficiency of an electric generator is expressed by the resistance of the outer circuit alone, divided by the total resistance. In the last example this is given in the expression,

$$\frac{1000}{1000+10}$$

or 99% nearly.

Such calculations are given in the mathematics of the science. The point to be established here is that relative resistances of conductors carrying constant currents define the expenditure of energy upon such conductors. The energy may appear as heat, as mechanical work, or as chemical decomposition. The work done is due to a fall of potential along a conductor, and the fall is determined by the relations of resistances.

The subject may be analyzed diagrammatically, remembering that the identical current goes through all parts of a circuit, and that all fractions of the line are subject to Ohm's law. Thus we may let a horizontal line represent the length of an electric circuit, say, 1,000 feet. At one end a vertical line may represent the total electromotive force. Obviously, then, a diagonal forming the hypothenuse of the triangle will represent the average falling of potential down the line of wire or other conductor.

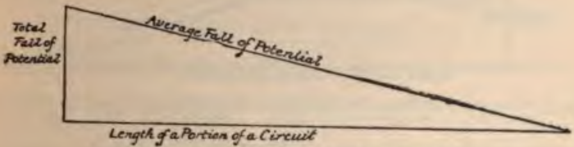

FIG. 4.—DIAGRAM OF FALL OF POTENTIAL.

But suppose that the line for equal lengths varies in resistance. Thus, assume that one-tenth the resistance is included in the first quarter, or 250 feet; then that 250 feet of fine wire are in the line, representing one-half the total resistance; then that the next 250 feet represents one-quarter of the total resistance; while the remaining resistance, or fifteen one-hundredths, is in the next and last section of 250 feet. Ohm's law tells us that the fall in potential varies with the resistance. Hence our diagram must show for the four parts of our line of 1,000 feet a fall proportional to the resistance of each section, The diagram produced in this way is given here. The angle of inclination of the separate lines indicates the fall of potential or electromotive force expended on each section.

This gives a pictorial representation of the conditions obtaining in a circuit of varying resistance.

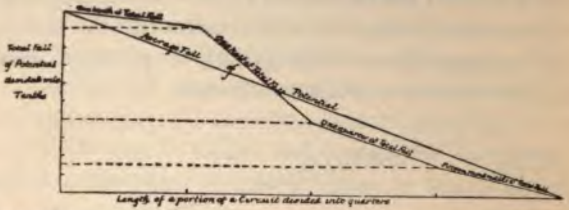
One tenth of Total Fall
Total Fall of Potential divided into Tenths
Average Fall of Potential
One half of Total Fall
One quarter of Total Fall
Fifteen hundredths of Total Fall
Length of a portion of a Circuit divided into quarters

FIG. 5.—DIAGRAM OF FALL OF POTENTIAL IN DIFFERENT PARTS OF CIRCUIT.

We might go a step further and graduate the thickness of the inclined line to represent the resistance. As resistance is in opposition to the current, the line should be made thin for high and thick for low resistance, as in the next cut.

The reciprocal of a number is the quotient obtained by dividing 1 by the number in question. The reciprocal of resistance is conductance. Hence, what was expressed in an indirect manner at the end of the last paragraph may be expressed directly in terms of conductance. The thickness of sections of the line may represent the conductance. This in the above case would give such a diagram as is given on the next page.

This diagram, which tells at a glance the whole story of the circuit, presents the analogy to a water conduit. The larger pipes manifestly require less head of water to convey the flow, and hence are represented less inclined. But the same quantity of water per hour or per second goes through all parts of the pipe, whatever its size.

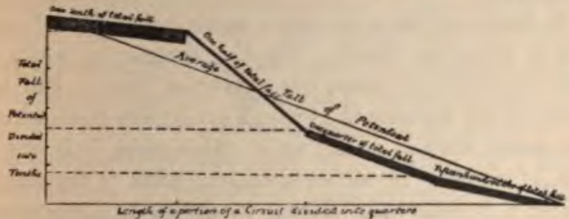
One tenth of total fall
One half of total fall
Average
Fall of Potential
One quarter of total fall
Fifteen hundredths of total fall
Total Fall of Potential Divided into Tenths
Length of a portion of a Circuit divided into quarters

FIG. 6.—DIAGRAM OF RELATIONS OF FALL OF POTENTIAL AND RESISTANCE.

The Velocity of Electricity.

The velocity of propagation of an electric disturbance, in the practical sense, is a variable quantity. The nature of the disturbance, and of the medium for its propagation, are all concerned in the question of the velocity of propagation of a signal. The frequent question, How fast does electricity travel? cannot be broadly answered. If the ether is momentarily thrown into and released from stress, or if its condition of stress is changed suddenly, a wave is started, exactly as when a stone is thrown into a quiet pond of water. This wave travels through space with the velocity of light, about 30,000,000,000 centimetres per second, which is about 185,000 miles. Its velocity under all conditions as far as known is invariable.

A wave travelling through space in all directions has a spherical front. On the surface of water a wave started by a stone has a circular front. But in going in all directions through space, the contour of any wave, such as an air or an ether wave, it is obvious, is circular in all sections, or, what is the same thing, it is spherical. Hence its intensity diminishes rapidly, varying inversely with the square of its distance from the point of origin. It is for this, as well as for other reasons, that the wave of electromagnetic disturbance, with its high velocity of transmission, cannot be readily utilized in telegraphy. The difficulty of concentrating such a wave into parallelism was to avoid the reduction of energy; and the interference of the curvature of the earth, coupled with the liability to interference with its path from other objects, has operated to render electromagnetic wave telegraphy of little practical use. The heliograph takes its place, with advantages of convenience and simplicity.

In practice the path of an electric disturbance or of the transmission of electric energy is determined by a wire or other conductor. The popular notion of the velocity of electricity is confined to the propagation of a disturbance, such as a telegraph signal, along a conductor. Now into this disturbance many elements enter. The line has to be charged, as in ordinary land telegraphy, so that its capacity for holding electricity on the surface of the wire is concerned. All along the line of the wire the ether stress is changed. As the phase of stress runs down the line it advances like a wave, but like a wave the progress of whose full development is retarded.

An uncharged line may be compared to a tube down which an impulse is to be given by a puff of air. A momentary blowing will send an impulse through the tube which will take a longer or shorter period to attain its full strength according to its capacity, or according to the intensity of the blowing. Pneumatic tubes have been used to ring bells, the impulse being given by squeezing a bulb at one end. This compressed the air and sent an impulse down the tube, which rang a bell.

It was at once found that the bulb had to have a large capacity compared to that of the tube, and small-bore tubes were naturally adopted for the purpose. In other words, small capacity of the pipe was found to be a great desideratum. It is precisely thus in electric telegraphy and general transmission of signals, telephoning, and other intermittent transmission. The smaller the capacity of the line, the better is the transmission of signals.

The question in both cases, it will be seen, is not how fast a steady current passes through a line, but how long a wavelike disturbance will take, under specific conditions of line capacity and strength of original impulse, to attain a given intensity.

In the case of the pneumatic signal tube and in the case of an electric telegraph the above condition exactly obtains. If one asks, How long does it take to send a signal across the Atlantic Ocean? the question is thus interpreted by the electrician: An impulse being started through the cable, how long will it take such impulse to attain sufficient intensity at the farther end to actuate the receiving apparatus? The elements entering are the electrostatic capacity of the line, the admissible strength of current that can be employed without injuring the cable, and the delicacy of the receiving instrument.

Thus, starting with an uncharged Atlantic cable, if a current was suddenly started through it one-hundredth ($\frac{1}{100}$) of the full strength would be felt at the farther end in about one-fifth of a second. Hence, with a delicate enough receiving instrument, this period would suffice for a signal to be transmitted. The current would go on charging the line of cable, and its intensity would increase at the farther end until, at the end of about 108 seconds, nine-tenths of its full strength would be felt at the distant end. With a very sluggish instrument used as a receiver, it is evident that even this period might be required for a signal to be sent across the ocean.

It is known that with fine-wire lines of small capacity a signal can be transmitted with approximately the velocity of light.

The ether in its wave actions and impulses shows qualities comparable to inertia. In the case of a magnetic metal, such as iron, an electromagnetic action is produced by a suddenly started current which requires energy and hence retards the wave in its transmission. The electrostatic qualities of the dielectric surrounding the wire, air or gutta-percha or other material, also affect the velocity, as naturally does the size of the wire.

It would seem that we would be justified in saying that in all cases the impulse would be transmitted in an infinitely small degree with the velocity of light. After this all the qualities and conditions named concur to determine the practical velocity of signal transmission.

CHAPTER IV.

FUNDAMENTAL UNITS AND THE RELATIONS BETWEEN ELECTROSTATIC AND ELECTROMAGNETIC UNITS —PRACTICAL UNITS: THE VOLT, OHM, COULOMB, AND AMPERE—ELECTRIC FORCE, WORK, AND ENERGY—CHEMISTRY OF THE CURRENT.

Fundamental Units and the Relations between Electrostatic and Electromagnetic Units.

When we do not know what a thing is, it is hard to conceive of a definite quantity of it. But our knowledge of electricity is derived from its effects. From the measurement of its effects, therefore, we can define a unit of quantity of electricity.

When two equally electrified bodies, or bodies charged with electricity, attract or repel each other with a force of one dyne when one centimetre apart, each one is charged with a quantity of electricity fixed by C.G.S. units. This quantity is the C.G.S. electrostatic unit of electricity. It is a perfectly defined unit, yet what it is that is measured is of course quite unknown.

If two bodies repel or attract each other with some other intensity and at some other distance, the quantity with which they are charged is easily determined. Suppose, for example, that a body charged with three units is attracted by one charged with six units. The total attraction of the six units of the second body for each one of the other three is obviously expressed by six, giving a total attraction expressible by six multiplied by three, giving eighteen.

The force, being a radiant one, varies inversely with the square of the distance. Hence, the attraction between two bodies, at any distance apart, must be divided by the square of that distance to reduce the interval to unity, provided the area of the bodies is small enough to keep them under this law of radiant force.

From these considerations the idea of different quantities can be conceived of. A body from its attraction for or repulsion from a definitely charged body—that is, a body charged with a known quantity of electricity—can readily have the quantity of its charge determined. It is this supposed ether stress that gives the basis for determining the unit in question.

If one C.G.S. electrostatic unit of quantity passes through a conductor every second, the current is of unit strength, and this is the electrostatic unit of current.

If the work done by this current in one second is equal to one dyne of force exerted over a path one centimetre long, which is one erg of work, the potentials of the ends of the conductor differ by one electrostatic unit of electromotive force.

If the conditions of the two suppositions of the preceding two paragraphs obtain, the conductor has one electrostatic unit of resistance. Any unit of current strength for electricity is such a unit as a gallon per second would be for water flowing through a conduit. Under the description of the ampere, more will be said upon this subject. The unit includes the idea of a definite quantity flowing per second of duration of the current. The electrostatic unit of current strength, often termed intensity, is therefore a current passing one of the units of quantity each second. If a current passes more or less, its intensity is determined by comparing it with the standard or unit current.

It is evident that from a unit current the unit of quantity can be deduced. It is the quantity which such a current passes in one second. In this way the electromagnetic unit is obtained. It is, though indirect, the most natural way, because current electricity is electricity in motion, and electromagnetic units are based on the latter form. The standard or unit current of the electromagnetic system is first determined, and from it the unit of quantity is derived, as given above.

A unit current in the electromagnetic system is one which, passing through one centimeter of wire bent into an arc of one centimeter radius, exerts a force of attraction or of repulsion of one dyne upon a magnet pole of unit strength placed at the centre of curvature of the arc of wire. Such a pole is one which exerts one dyne attraction or repulsion at a distance of one centimetre upon a similar magnetic pole.

Such current passes in one second one electromagnetic unit of quantity. This deduction, it will be seen, is exactly the converse of the deduction of the electrostatic unit of current.

When it is known that there are two complete systems of C.G.S. electric units—one the electrostatic, the other the electromagnetic—based upon these two fundamental reactions, the interest and importance of their relation to each other is obvious. The comprehension of such relation also brings out the theory of electricity well, and gives a species of proof of the velocity of the electric current. It is a pity that it is not better understood, for certain difficulties attend upon the theory of its explanation.

It is found that the electromagnetic unit of quantity is 30,000,000,000 times greater than the corresponding electrostatic unit. The explanation would be easy were electrostatic and electromagnetic lines of force identical in all respects; but it is definitely certain that they are not the same. An electrostatically charged body does not attract or repel a magnet, and a magnetic pole does not attract or repel an electrostatically charged body. Even this need not prove different ultimate and intrinsic qualities of the two kinds of lines of force. But we see no reason for believing, *per se*, that the electrostatic line of force is a series of molecular whirls or currents, such as the electromagnetic lines seem probably to be.

It is generally believed that if a charged body were carried through space with sufficient velocity, *i.e.*, with the velocity of the electric current or of electric waves, it would act, as regards induction, like a wire carrying a current.

The general statement of the relation of the two systems of units, and its connection with the velocity of propagation of ether waves, which may be waves of any form of radiant energy—light, heat, or electricity—is this:

The repulsive or attractive force of the centimetre of wire passing a unit current is equal to that of the unit electrostatically charged body. The same quantity of electricity is present in each; or one centimetre of wire passing a unit current contains, as long as the current passes, one electrostatic unit of electricity. The question now is, How many electrostatic units of quantity pass through the wire per second? Obviously they are as many as the centimetres of wire which the current passes through per second. If all the assumptions made above are correct, then the relation of electrostatic to the electromagnetic units gives the velocity of electricity in current form.

This may be made more clear by a recurrence to the hydraulic analogy. Suppose a pipe is of such size that one lineal foot of it contains a pint of water when full. Suppose a current of water is going through it at a given number of feet per second. It is clear that the units of quantity, in this case pints of water, carried by such a current per second will be equal to the number of feet per second which it travels.

The velocity of the electric current is supposed to be 30,000,000,000 centimetres per second. The electromagnetic units of quantity and of current strength are as many times larger than the electrostatic units as the current travels centimetres per second.

This view brings out the difference between the two modifications of electricity, the electrostatic and electrodynamic forms. One is electricity in repose, the other is electricity in motion.

If, by trying the experiment, the length of wire passing an electrostatic unit current of electricity were determined, which wire would exert a dyne attraction or repulsion upon a unit magnet pole at unit distance, the length of such wire would give the velocity of the current. This would follow from the fact that one electromagnetic unit of quantity must be present at each instant, and always in the entire length of wire, since it exerts the force of one electromagnetic unit. It would be thirty thousand millions of centimetres long.

Thus, supposing our water pipe to pass one pint of water per second, the velocity of the stream would be equal to the length of pipe over which one pint was distributed.

The velocity of light is found by experiment to be equal to 30,000,000,000 centimetres per second. This is the velocity of the electric current deduced from or explained in the above considerations. It is one of the reasons for believing light and electricity to be in the same order of forces, and is one of the grounds for the upholding of Clerk Maxwell's electromagnetic theory of light. It justifies the use of the hypothetical luminiferous ether in explaining electricity, as well as light.

It is to be noted here that the velocity given above is more accurately defined as the velocity of propagation of an electromagnetic wave through the ether. The velocity of a current is really undeterminable, except by the admission of some such hypothesis as the identity, in effect, of a current and of an electrostatically charged body moving with current velocity.

Practical Units—the Volt, Ohm, Coulomb, and Ampere.

We have already spoken of some fundamental units of mechanics. In practical work no one would use these numbers, on account of their inconvenient size. The same applies to electricity. There are the two complete series of electrical units, based on the centimetre, gram, and second, which have been described in part as examples of the fundamental or C.G.S. units, but which are not used to any extent practically.

These two fundamental systems are the electrostatic and electromagnetic systems of electric units.

Taking the electromagnetic fundamental units as the primary ones, from them the practical units are derived by the following process: Instead of being based upon the centimetre, gram, and second, the practical units are founded on the following quantities: (1) One thousand million centimetres, (2) the one-hundred-thousand-millionth of a gram, and (3) the second. In powers of ten these numbers are expressed briefly as follows: (1) 10^9 centimetre, (2) 10^{-11} gram, (3) 1 second. The units are 10^9C. 10^{-11}G. S. units.

If for the centimetre and gram we substitute these multiples of them, the practical units may be deduced exactly as were the fundamental ones. There is a series of such units which threatens to become inconveniently long; but without entering into the mathematics of the science, some concrete idea of the meaning of the three most familiar of the practical units may be given here.

The volt is the practical unit of electromotive force, or of difference of potential. If we recur to our reservoirs of water, we should find a foot height of water a very convenient term to use as a unit of difference of height or of head of water. Such unit, one foot of head, is in constant use by all engineers. This is a precise analogy to the volt, which is the unit which measures the tendency of an electric charge to escape to its opposite or bound charge, which tendency is the actuating force of currents, or is electromotive force. The volt is the cause of a current, but is not an attribute of it. It is the attribute of a circuit. The expression once so prevalent, even with those supposed to be electricians, of a thousand-volt current or a hundred-volt current were incorrect and absurd. It would be almost as bad to speak of a thousand-pounds-to-the-square inch-flow or current of water. On the other hand, it would be correct to speak of a thousand-pounds-to-the-square-inch system of water-works or of a one thousand- or one hundred-volt electric circuit.

A very familiar battery is the Daniell combination. It is made by immersing a plate of zinc in zinc sulphate solution and a plate of copper in copper-sulphate solution, all in one vessel, the solutions being sometimes separated by a porous diaphragm. It can be seen in almost all telegraph offices in a modification called the "gravity" cell, in which the diaphragm is omitted. A battery is a contrivance which converts chemical energy into electrical energy, and which maintains a difference of potential between the surfaces of the opposite plates. The Daniell combination maintains a difference of one and sevenone-hundredths volts between the surfaces of its plates.

The unit of resistance is called the ohm. Everything has electrical resistance. Some things have an almost immeasurable resistance, or offer an immensely powerful barrier to the passage of a current. Such are called insulators. Yet everything conducts to some extent; and when an insulator is spoken of, it is only a relative term. The best insulator under the smallest electromotive force will carry a current.

A column of mercury one square millimetre in cross-section and 1.0624 metre long has the resistance of one ohm.

The practical unit of quantity is the coulomb.

Take a conductor of resistance of one ohm, say our mercury column, and maintain a difference of potential of one volt between its ends, and in one second one coulomb would pass through it.

The practical unit of current strength or intensity is the ampere, also a much-abused term. It is the current of one coulomb per second, one which would be maintained through a resistance of one ohm by one volt potential difference between its ends. The combination just cited for the coulomb, therefore, involves a current of one ampere.

A copper wire nine one-hundredths ($\frac{9}{100}$) of an inch in diameter and eight hundred and thirty (830) feet long, connected between the terminals of a

Daniell cell of no resistance, which would be one of infinite size, would pass a current of one ampere. Such a cell is of course inconceivable. A dynamo of negligible resistance might easily be used to maintain the requisite potential difference (1.07 volts) for the above wire.

A greater potential difference will maintain through the same resistance an exactly proportionately greater current, and *vice versa;* a greater resistance will diminish the current in exact proportion, and *vice versa.*

The ampere is a unit of rate, and the expression of one or ten amperes per second is redundant and useless.

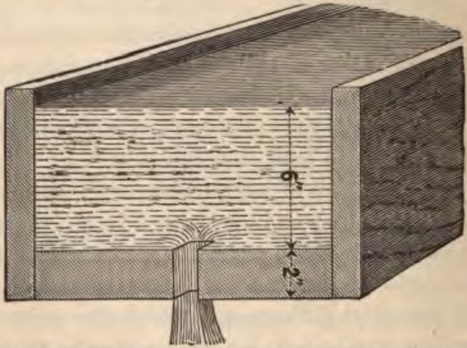

FIG. 7.—THE MINER'S INCH AS AN ANALOGY FOR THE AMPERE.

The ampere is exactly analogous to a well-known unit of water flow, the "miner's inch." This is a unit used by miners and irrigators in the Western and Pacific States. It denotes the rate of flow of water which, under a head of six inches, will pass through a hole one inch square in a board two inches thick. Let this head of water represent a volt, and let the resistance of the hole represent an ohm; then the miner's inch would represent a current of one ampere. One miner's inch per second or per hour is redundant, as everything is said when the simple "inch" is expressed. It may flow for a second or an hour. As we may speak of an "ampere-second," a compound unit, which we have just seen is the coulomb, so we may speak of a "miner's inch-second," which is .1937 gallon of water.

Electric Force, Work, and Energy.

Energy and work in the mechanical world are in practice expressed in compound units, each composed of a unit of fall or rise multiplied by a unit of weight such as a foot-pound. Electrical work and energy are expressed in compound units each composed of a unit of quantity of electricity multiplied by a unit of fall or rise of potential. Thus energy is said to be expended in raising a quantity of electricity from a lower to a higher potential.

The assertion is fair enough as an analogy, but it is often used as an expression of fact. This is going rather too far, unless the force of the expression "raising" be strictly limited to effecting a change of potential.

Taking a volt as the unit of potential and a coulomb as the unit of quantity, the volt-coulomb is the practical unit of electrical energy or work.

Taking now, as before, a triangle as the repesentation of a closed active circuit, we recognize in it two phases—one the expenditure of work, the other the expenditure of energy. Down the incline the ten units of potential, forcing a given quantity of electricity per second through the resistance of the line, expend energy and do work. The work may appear as and be expended in the heating of material, running motors, etc. The energy thus absorbed has to be supplied; and this is done by the generator or battery, which doing work develops electrical energy up the perpendicular element, keeping to the triangle as a representation of the operations.

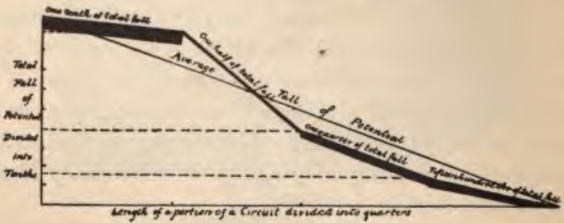
One tenth of total fall
One half of total fall
Average
Fall of Potential
One quarter of total fall
Fifteen hundredths of total fall
Total Fall of Potential Divided into Tenths
Length of a portion of a Circuit divided into quarters

FIG. 8.

The inclined path may be assumed to represent a road down which a carriage rolls. The broad lines represent a good road, the narrow lines a bad one, To maintain a constant speed, it is evident that the inclination must vary with the quality of the road. Thus, the carriage will use up more or less of its energy of descent according to the quality of the track it follows, provided it is compelled, as is the electric current, to maintain a constant rate.

After going down the incline, thereby expending its potential energy, the carriage has to be restored to its original position to repeat its course. This requires it to be raised up the vertical, which corresponds to the work of the battery in raising the fixed quantity of electricity back to its starting-point.

The analogy is imperfect unless a series of carriages, balls, or wheels perpetually going around the circuit is thought of. The flow of an electric current is continuous.

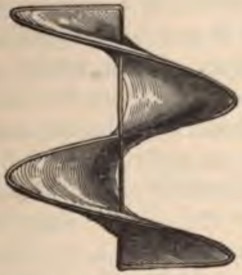

FIG. 9.

A spiral line such as shown in the cut may be taken to indicate the fall of potential in a system; the work of the battery will be represented by the vertical line. As the battery raises the potential, it is expended in the descent of the current down the spiral grade.

Mechanical rate of work is measured by foot-pounds per minute, or by any other unit involving height, weight, and time. Electrical rate of work is measured by a unit involving potential difference, quantity of electricity, and time. Thus, taking the units we have been using, we have as a rate of work unit a volt-coulomb per second, which is the same as a volt-ampere.

A mechanical horse-power is 550 foot-pounds per second; an electrical horse-power is 746 volt-coulombs per second, which is the same as 746 volt-amperes.

The energy carried by a wire may seem an intangible thing, but it can be determined by a method simple in principle. When a wire carries a current, the fall of potential between its ends is determined by regular methods, as is also the current which goes through it. By multiplying the fall of potential by the current, the electric energy absorbed by the wire is ascertained. The heat energy corresponding thereto is ascertained by placing the conductor in a water or other calorimeter and determining the amount of heat units produced.

On this or on a similar basis the efficiency of dynamos and other generators is ascertained. The energy supplied to a mechanical generator, such as a dynamo, is determined in mechanical units such as horse-powers. Then, it being known how many electrical units correspond thereto and how many the dynamo produces, its efficiency is at once given.

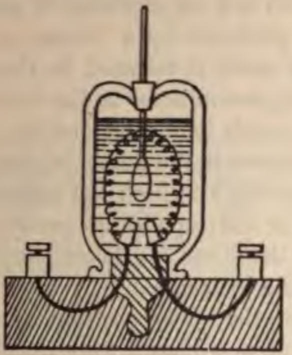

FIG. 10.—CALORIMETER.

The Chemistry of the Current.

An electrolyte is a liquid which is decomposible by the electric current and which necessarily is a conductor of electricity.

An electric current which has an electrolyte included in its circuit effects a chemical decomposition of the electrolyte if the conditions are proper, or adapted for such action. These conditions are absolutely definite, and the decomposition can be exactly predicated of any given set of conditions.

In a battery we see a decomposition effected, and the same action can be produced in another solution by a current produced by a battery or by any other means. It is easily illustrated in the experimental way by cutting a conductor at the desired place, and immersing its ends in the electrolyte. The electrolyte is decomposed if the potential difference is great enough. The end by which the current enters takes the oxygen or corresponding portion of the substance, while the other end takes the element corresponding to the hydrogen.

The case of the decomposition of water may be taken. In a glass is placed water, made a conductor by the addition of caustic soda, sulphuric acid, or other compound not too easily decomposed itself.

To the ends of the conductors plates or wires of some conductor not attacked by the decomposing electrolyte are attached. To produce a more rapid action it is well to make these large. If of wire, its exposed end may be wound into a coil. In dilute sulphuric acid plates of platinum are generally used; in caustic-soda solution, iron acts excellently.

The ends thus prepared are immersed in the water, and about two volts difference of potential are established between the two. As the current passes by electrolytic conduction, the water is decomposed into its constituent gases. From the end by which the current enters, oxygen escapes; from the other, hydrogen. The molecules travel, giving up one constituent to one electrode and the other to the second electrode as somewhat crudely shown here. They may be collected, if desired, in separate tubes or vessels, as shown. Although the water prepared for the experiment is a conductor, and can act as such with low potential difference, if the potential difference passes a certain point, absolutely fixed for water as well as for other compounds, but differing for each specific decomposition more or less, it acts as an electrolyte, and conducts electrolytically only; it ceases to act as a common conductor. The vol-

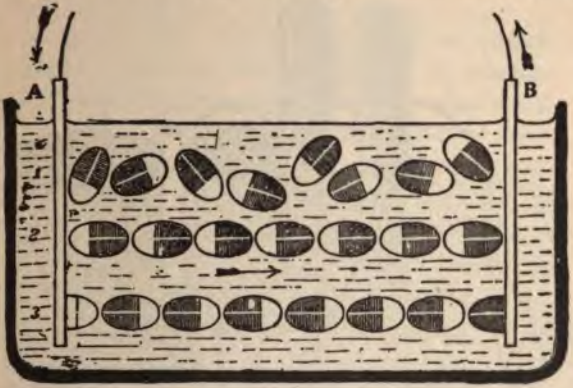

FIG. 11.—THEORETICAL POLARIZATION AND DECOMPOSITION OF MOLECULES OF WATER.

ume of gases given off is exactly proportional to the quantity of electricity passed by the current.

By carrying out the decomposition in a closed vessel the gases will be set free and will accumulate under pressure. The most enormous pressures can thus be developed by the silent and unseen agency of the current. Two common gravity cells such as used in a telegraph office could burst a cannon shell.

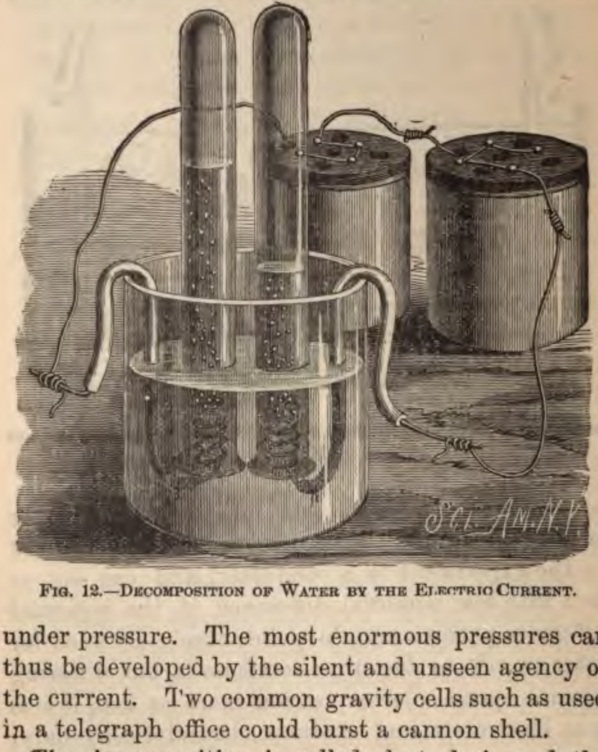

Fig. 12.—Decomposition of Water by the Electric Current.

The decomposition is called electrolysis, and the immersed plates or ends are called electrodes. The plate attracting the oxygen is called the anode, the one attracting the hydrogen is called the cathode. All the nomenclature is rather cumbrous, and not very easy to remember.

The same principles carried out for other chemicals brings about other decompositions. A solution of copper sulphate gives copper to the cathode and sulphuric acid to the anode. Silver cyanide in solution gives silver to the cathode, and the decomposition of an immense number of compounds have been elaborately investigated with regard to their heat of combination and decomposition, which are equal and equivalents, or rather reciprocals, of each other. To a definite heat of combination a definite voltage or potential difference corresponds. All these points have their place in the mathematics of electricity.

The electrolyte, with its electrodes and cup containing it, when decomposed by a battery really represents a second battery often in accord with the regular battery, as regards its polarity or direction of current, which it then would aid in producing. Sometimes it acts against the battery, producing what is called counter-electromotive force; and this condition is sometimes brought about after decomposition has been going on for some time. In the storage battery, from the start, the current it would produce is opposed in direction to the charging current. Each cell has about two and one quarter volts counter-electromotive force.

By this principle of electrolytic decomposition the electroplating of surfaces is executed. The most varied effects and curious methods may thus be carried out. Of course its application to silver and nickel plating, as well as to other metals, is familiar and does not require mention here.

Among the curious processes may be mentioned the electroplating of flowers and insects. By giving these a delicate coating of some material which will conduct the current, and attaching to them the wire from the zinc plate of a battery or from any source of electrical current, while the corresponding electrode is attached to the other wire, and by then immersing both in a proper solution, the object will be plated with silver, gold, or copper as the case may be, giving a beautiful metallic flower, leaf, or insect. The most varied objects, large and small, have thus been reproduced. Some have even gone so far as to suggest the electroplating of corpses, and it is certain that a death-mask, as the sculptors call it, could be thus effectually produced.

Another ingenious application has been proposed for making complicated and hollow objects. Copper, for instance, may be electrically deposited upon a core of a fusible alloy, and the core afterwards may be melted out. This has been proposed as a method of constructing Argand gas burners.

Dissimilar substances such as platinum and carbon filaments can be connected by the electric deposition of a metal upon and over their junction. This process, termed electric soldering, is used in making incandescent lamps.

If an object is slightly oiled, the electric deposition can be removed if the object is not "undercut," or is not of such shape as to prevent it. Thus a reverse of the object is produced, upon which as a model a second deposition can be made, giving the reproduction of the original.

What is most striking about an electrolyte is that except for electrolytic conduction it passes no current. If enough potential difference is maintained between two electrodes immersed in it to effect its decomposition, the current it will apparently pass will be exactly porportional to the decomposition effected. For a given number of coulombs there will be precisely a known weight of hydrogen set free if the solution is water, for instance. But the electrolyte must itself be a true conductor, and must have the power of actually conducting a current of lower potential. Thus chemically pure water is not an electrolyte because not a conductor.

CHAPTER V.

THE MAGNETIC CIRCUIT AND ELECTROMAGNETIC LINES OF FORCE—MAGNETS AND AMPÈRE'S THEORY.

The Magnetic Circuit. Electromagnetic Lines of Force.

WHEN two bodies are oppositely electrified, a stress is produced in the ether in their neighborhood which is represented by the figurative expression, "lines of force." Faraday's great work consisted in determining the extent of the sphere of electrical action, showing that it was not confined to conductors, but that by far the most of it operated outside of conductors. Something has already been said of lines of force. A theory of the constitution of an electromagnetic line of force may be here shown. The term electromagnetic lines of force has a definite meaning, which involves a distinction from electrostatic lines of force. A magnet or a piece of steel which has been polarized is affected by the electromagnetic stress, and tends to place itself parallel to its direction; and if the magnet is used, the north pole will always tend in the same direction with respect to the polarity of an electromagnetic line.

The electrostatic line of force, on the other hand not affecting the magnet or iron filings, is evidently different in constitution.

Because of their action upon magnets or iron filings, electromagnetic lines of force are more readily pictured to the mind. In this there is an element of danger, as the term "line" is only used as a matter of convenience.

Unless otherwise specified, what is here said aplies only to electromagnetic lines of force.

A line of force is supposed to represent the axis of a series of whirls of ether, which whirls are of molecular size. Thus, a series of curtain rings might be strung upon a stretched thread and caused to rotate around it. This would give some idea of the constitution of a line of force, and the thread would give its direction and its conventional representation as a simple line.

The whirling of such a ring may be produced by stringing one or two curtain rings upon a piece of wire, which is then tightly stretched. On plucking the wire with the finger or sounding it with a violin bow, the ring will whirl around with extraordinary velocity, showing a very pretty figure by the reflection of light from its bright surface. The same may be shown by a piece of string with a ring or even a button strung upon it. If such is stretched between the two hands, the same representation can be produced. All this, of course, is merely a crude pictorial representation or model of the supposed constitution of one of the whirls of an electromagnetic line of force.

The direction and polarity of the lines of an actual magnetic field are easily studied. Without detracting from Faraday's unparalleled genius and work in this field, the ease with which electromagnetic lines of force can be mapped out and investigated conduced largely to the success of his investigations.

Lines of force are studied most easily by the use of iron filings. These tend to arrange themselves parallel to and as nearly as possible in the axis of the lines. The field of force around a magnet is shown by placing a piece of paper over it, dusting

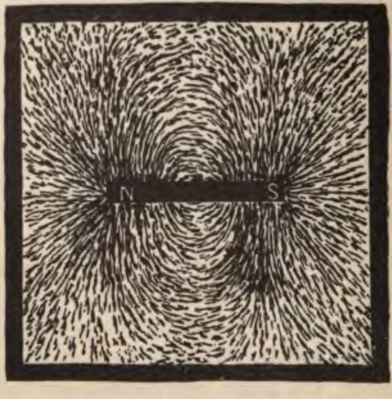

FIG. 13.—ELECTROMAGNETIC LINES OF FORCE SHOWN BY IRON FILINGS.

iron filings upon the paper, and tapping it. The filings take a symmetrical position, and show that lines of force connect the opposite poles of the magnet. An example of this experiment is shown in the first cut, and the diagrammatical representation in the next cut.

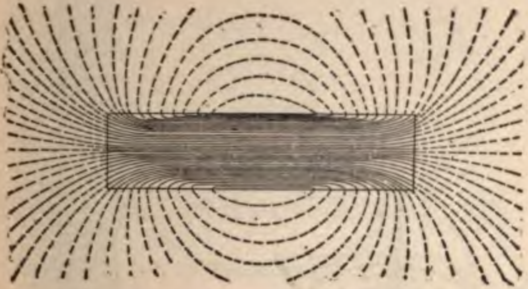

FIG. 14.—DIAGRAM OF PATHS OF LINES OF FORCE OF A BAR MAGNET.

The circular lines of force which surround a wire carrying a current are shown by passing the wire through a horizontal card, upon which filings treated as above arrange themselves in circles. The diagram Fig. 18 shows the conception of the constitution of such lines of force, with their surrounding whirls.

Lines of force possess several peculiar characteristics. One is that in air and most other mediums they are influenced by a tendency to separate from each other, but at the same time tend to take as short paths as possible. This separation is due to the fact that air is a poor conductor for lines of force, or its permeance is low; hence they spread about in order to go through as large a mass of air as possible. Another characteristic is that in iron and in one or two other metals this diverging tendency is much less marked; and if a piece of such substance be placed in the path of lines of force, a portion of them will crowd together into it, leaving their normal paths through the air for the better medium, iron, nickel, or cobalt. This is because the metals in question have high permeance for lines of force.

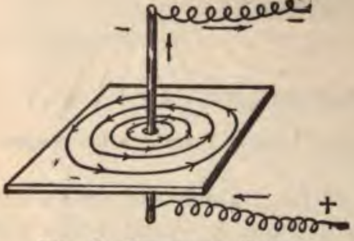

FIG. 15.—EXPERIMENT SHOWING LINES OF FORCE SURROUNDING AN ACTIVE CONDUCTOR.

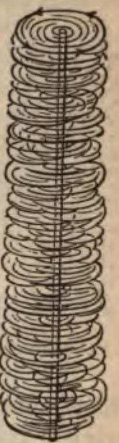

FIG. 16.—DIAGRAM OF LINES OF FORCE SURROUNDING AN ACTIVE CONDUCTOR.

Lines of force must go from somewhere to somewhere. In the case of a magnet they go in a general sense from pole to pole, as shown in the cut. They are assumed, in the case of a magnet, to also go through the metal itself. They do not in this case all emerge from the poles. A multitude of lines start from all parts of the magnet and enter at corresponding points on the other side of its centre or neutral point. They may be traced by a small compass whose needle tends always to lie parallel with a line of force.

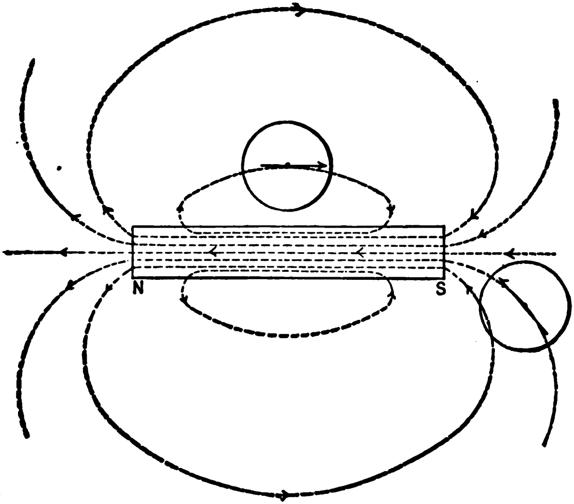

Fig. 17.—Use of a Compass in Tracing Lines of Force.

Every line, therefore, can be traced through a circuit. The magnet with its lines of force represents what is known as a magnetic circuit. As magnetic polarization cannot be imparted to iron without creation of both north and south poles, and as a line of force starting from a north pole must return to a south pole, no magnetic lines of force can be established without the formation of a magnetic circuit.

Here a difference from electrostatic lines of force appears. Every electrostatic charge is bound—that is, has an opposite and equal charge—somewhere. To this its lines of force go; but there is no circuit, there is only a connection.

Lines of force in a magnetic circuit start from and return to all parts of the magnet except its centre. All the parts of a magnet removed from the centre or neutral point have magnetism, and, if on different sides of the neutral point, are said to be of different magnetic potential, exactly as in the case of electric circuits. Hence this starting of lines from the sides as well as ends of the magnet is perfectly natural.

The point is that only the centre of a regularly magnetized bar is without magnetism. If we go the least distance toward its north pole, starting from such central or neutral line, north polarity will be discovered, and the reverse if we explore toward the north pole. Difference of magnetic potential simply expresses the condition of any two points of a magnet at unequal distances from the neutral line, or at equal distances on opposite sides. A line of force starting from a point of given north polarity will return to a point of equal south polarity, but not to a point of higher or lower north polarity.

The perfectly circular line of force is such as those surrounding a wire carrying a current. Its mechanical analogue is seen in a smoke ring. These are easily made by cutting a hole in the side of a paper box, filling the box with smoke and gently tapping its side. This will cause smoke rings to issue, which have a whirling motion around the circular axis of the ring shown in the diagram. Phosphureted hydrogen, inflaming spontaneously in air, shows the shape and rotary motion much better. Such are called vortex rings.

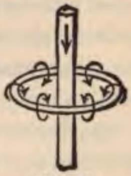

FIG. 18.

The reason for asserting that lines of force have this electric whirl around them is that an electric current though a circular conductor creates lines of force within the area surrounded by it, and perpendicular to the plane of such circle.

It is certain and evident that lines of force are maintained without the expenditure of energy. This would seem to offer a difficulty but for one thing—that we can assume that the electric whirls are of molecular dimensions, and that their current exists through a circuit of zero resistance, and hence represent the expenditure of no energy.

A curious coincidence and perhaps true analogy is to be remarked here. One of the attempts at figuring the molecules of matter has centred in the vortex ring, as it is called, which has just been described. This ring possesses various striking peculiarities which give it some resemblance to the supposed ultimate molecule of matter. Now, in the electric world we find such rings, no longer of molecular size but only of molecular thickness, surrounding an electric current, and distorted lines of such whirls or rings emanate from and return to points of opposite polarity in a magnet.

As, for the sake of convenience, a positive and negative quality is attributed to electricity, and the direction of the current is assumed to be from positively charged to negatively charged objects, so in the case of lines of force emanating from a magnet a direction is assigned to them. They are assumed to go from positive (north) to negative (south) pole of the magnet which creates them as indicated in the cut Fig 17.

Magnets and Ampère's Theory.

Every one is familiar with the magnet. It is put as a toy into the hands of children. It is found by them to attract steel; and if they go far in their experimenting they find that like poles of two magnets repel and unlike poles attract each other.

It appears to be an endless source of energy, but this, of course, is impossible. It is a seat of force only, and in a certain sense can be made to store up or accumulate energy. The attraction and moving of its armature or other piece of iron to its polar surface requires the expenditure of energy. When such is drawn away from it, the work of so doing stores up energy in the magnet for the next attraction. If a magnet was made and allowed to attract an armature through a distance, its attractive force should theoretically be thereafter that much weaker, and no more, because separation of the armature would store up energy for the next attraction. But for the first attraction no special energy was stored.

The fact that a magnet is not a seat of energy has not always been realized, and efforts are still made by inventors not conversant with electricity to utilize the magnet as a source of power. If this were possible, then perpetual motion would be discovered. Inquiries are often propounded as to what substance will cut off magnetic influence. This can only be done by some polarizable material which in itself will constitute an armature. The mere attraction of an armature and its retention only requires the exertion of force; the motion of an armature against a resistance such as its lifting through space requires energy. This distinction is important and too little appreciated. A magnet holding its armature attracted does no work.

When a bar of iron is wound with wire, insulated or otherwise prevented from touching the iron and with its spirals not touching each other, the iron becomes a magnet. It attracts iron and steel, each end repels one pole and attracts the other pole of a compass needle or other magnet, and it shows lines of force reaching from pole to pole and in general the indications of possessing magnetism or of being polarized.

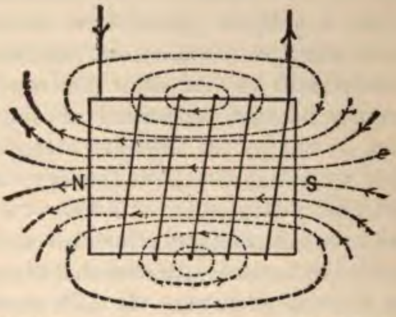

FIG. 19.—ELECTRO-MAGNET DEVELOPING LINES OF FORCE.

If instead of iron a piece of steel is taken and treated thus, the effects are the same in general, except that a large portion of the imparted magnetism is permanent, and remains after the current has ceased.

It is found also that the magnet thus made possesses north and south poles, or, if suspended by a fine thread, or if floated on a cork on water, will point north and south approximately, and the same end will always seek the north pole and the other the south pole of the earth. The poles are found to be formed on one or the other end, according to the direction of the current which excited the bar to magnetism.

If the observer is imagined as facing one of the poles of a bar wound with wire as described, it is evident that the current may be supposed to go in the direction of the movement of the hands of a clock or watch—"clockwise"—or the reverse. If the current goes clockwise, then the pole facing the observer is a south pole. If the current goes against the direction of the clock's hands, then it is a north pole. This is shown in the cut Fig. 19.

Thus, by varying the direction of a current, any polarity desired may be produced.

When a magnet is thus produced, the lines of force are also formed with all their characteristics. There is absolutely no difference between a permanent and current-formed or electromagnet, except that the latter may be made much stronger than a permanent one.

These facts give the basis for the famous Ampèrean theory of magnetism, devised by André Marie Ampère, the French scientist, from whom the practical unit of electric current-intensity is named.

A permanent magnet is supposed to be a *locus* around which electric currents are perpetually circulating in the direction of the hands of a clock if one faces the south pole or negative end. As a permanent magnet is not a seat of energy but of force, only the currents may be supposed to virtually consist of an aggregation of molecular whirls in circuits of no resistance, and of molecular size, exactly as in lines of force in the air or any medium. Thus the cut shows at A the north pole and at B the south pole of a magnet, and *a b* and *c* represent the minute active circuits.

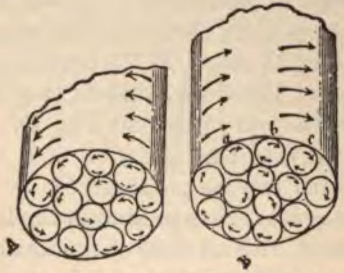

FIG. 20.—NORTH AND SOUTH POLES OF A MAGNET TO ILLUSTRATE AMPERE'S THEORY.

Two currents going in the same direction tend to place themselves parallel. The earth's polarity by the Ampèrean theory is accounted for by assuming it to be girdled by electric currents approximately in planes parallel to the equator, and going from east to west, opposite in direction to those encircling a magnet whose north pole is pointing north. The tendency of the nearer portions of the two sets of circular currents, one around the earth, the other around the magnet, to coincide in direction, and to be parallel, causes the magnet to point north and south. The earth currents may involve the expenditure of energy, and probably do. Poor conductor as the surface of the earth may be, its interior may be better; and in any case the great volume of the earth would compensate for its normally high resistance.

As amber was the material with which the first experiment in static electricity was performed, and gave its name to the science, so the natural loadstone was the first magnet experimented with. It was found at Magnesia in Asia Minor, and the name "magnet" is derived from that of the locality.

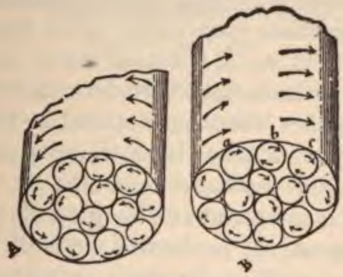

FIG. 21.

If we follow out the fact that currents in the same direction attract each other, the same diagram will show that the opposite poles of magnets should attract each other for the same reason. The direction of the theoretical Amperean currents in a magnet being in opposite directions at the two poles, it is evident that when opposite poles are brought face to face the Ampèrean currents will coincide in direction.

To an observer facing the north pole of the earth, the Ampèrean earth currents would seem to go in the direction of the hands of a watch. Thence it follows that, if the earth be considered a gigantic magnet, what we call its north pole would be really its negative or south pole. The confusion would be avoided if we call the positive pole of a magnet, the "north-seeking," instead of north pole, and *vice versa.*

Again, if the earth is a magnet, lines of force should emanate from it, running from pole to pole, and from intermediate spots south of the magnetic equator to points of equal potential north of the equator. Such lines of force have been proved to exist and by inductive action like that exercised by the field magnets of a dynamo upon its rotating armature a current is readily produced from them. The simple rotation of a coil about an axis properly placed is all that is necessary to produce a current. Such a coil is termed an earth coil and an example of one with galvanometer in the circuit is shown in Fig. 22.

The lines of force should vary in intensity from the magnetic equator toward the magnetic poles, and a given earth coil rotated at a fixed rate should give different currents, those of greater intensity as it is nearer to the magnetic poles. This is the case in fact, and is shown also in the varying directive power of the earth upon a magnet.

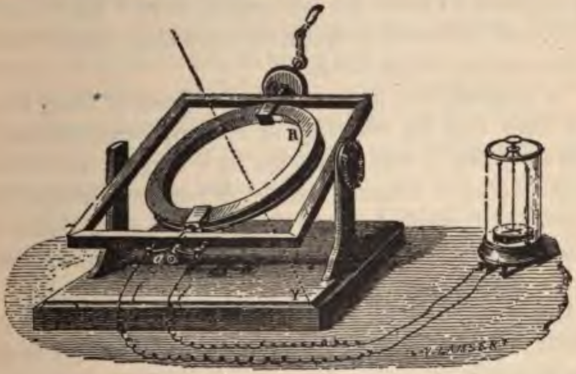

FIG. 22.—EARTH COIL.

On the earth's surface matters would be simplified if the Ampèrean currents coincided with the parallels of latitude. Then the true equator would mark the neutral line or magnetic equator, and the magnetic poles would coincide with the poles of revolution. This is not the case, however. The Ampèrean earth currents are slightly irregular, so that the magnet or compass needle in placing itself at right angles to these currents will not, except at particular places, point north. Thus, the magnetic poles of the earth, determined by the intersection of verticals to the Ampèrean current lines, do not coincide with the true poles. The irregularity also is in a perpetual state of change.

The compass needle, in seeking the magnetic poles, also tends to leave the horizontal, or to " dip," showing that the poles in question have their *locus* below the surface of the earth.

A magnet, it is known, attracts a mass of inert iron. It does this by creating in it Ampèrean currents. Every piece of iron acted on by a magnet is for the time being a magnet itself. When iron filings are used to illustrate lines of force, or when a paper of tacks is emptied out upon a table, and is picked up by a magnet, every particle of iron is for the time being a magnet, its polarity being determined by its relation to the magnet. Each molecule of the tacks or filings is the seat of an Ampèrean current. The same remark applies to filings used to show the current lines of force. Each filing is for the moment a magnet.

Just as a magnet places itself at right angles to the earth currents, so it tends to place itself at right angles to artificial currents of electricity. Thus, a compass, brought near to a wire, indicates by its behavior whether a current is passing through the wire or not. By referring its movement to the Ampèrean currents, and remembering that the effort is for currents similar in direction to be parallel, the direction of the current can be told by the movement of the needle. Of course if the wire lies in the magnetic parallel, it will be without effect on the compass needle, except to intensify or diminish its directive tendency. If it runs north and south and above the needle and deflects the north-seeking pole of the magnet to the east, then the current flows south; if to the west, it flows north.

It is on this principle that most instruments for measuring currents, such as galvanometers, amperemeters (or ammeters for brevity), and voltmeters, are constructed. The latter, although used for determining potential difference, do it by measuring the current passing through their coil, and to that extent are amperemeters also.

Some telegraph instruments, especially English ones, are based on this principle. Cable messages are often received by an instrument of this class, a reflecting galvanometer.

CHAPTER VI.

ELECTROMAGNETIC INDUCTION AND ACTION OF CURRENTS UPON EACH OTHER—THE INDUCTION COIL AND ITS APPLICATIONS.

Electromagnetic Induction and Action of Currents upon Each Other.

INDUCTION is a phenomenon of action at a distance which was spoken of in the beginning of this work. A body receiving upon its face a charge of one kind of electricity immediately induces an opposite and equal charge somewhere else, which is bound to it by electrostatic lines of force. This is electrostatic induction, and it continues as long as either body retains its charge or any fraction of it. Again, the attraction of a magnet for its armature, involving the conversion of that armature into a magnet for the time of contact or influence, is a form of induction. Both these are examples of the exercise of force by induction; in electromagnetic current induction we frequently deal with the exercise of great energy by induction.

If a wire through which a current is passing lies near to and parallel with part of another wire, which last-named wire is bent into a complete or closed circuit, no action takes place unless the current strength in the first wire is varied, or the distance between the wires or their relative positions are altered. Then a momentary current at once is excited in the second wire. This is electromagnetic current induction.

Further than what has been said, nothing need be said about electrostatic charges and electrostatic induction. Electromagnetic induction is of more importance in the practical world, and will be spoken of here.

It is the form of induction which owes its existence to electromagnetic lines of force, such as those which have already been spoken of.

Electromagnetic induction is of importance in the every-day world, because upon it depends nearly all the recent work in electricity. The immense development of the science witnessed in the last two decades is due to the development of apparatus based on this particular form of induction. The single fact that dynamos and motors depend upon it for their action shows how practical a thing it is.

In this chapter, when the word induction is used without qualification, electromagnetic induction will be meant.

The first conception of induction may be taken from two parallel wires conducting currents. They may attract or repel each other, but will never be neutral. As we have seen, both are surrounded by ring-shaped or annular lines of force, of definite polarity, dependent on the direction of the current.

If the current in both wires is in the same direction, they will attract each other. This attraction may be referred to the annular lines of force. A moment's reflection, even without the aid of any diagram, will show that the portions of the lines of force nearest each other are of opposite polarity. Each annulus being of like total polarity, tangential portions are of opposite. Two wheels rotating in the same direction, if brought together, will have the portions of their peripheries which are in contact moving in opposite directions.

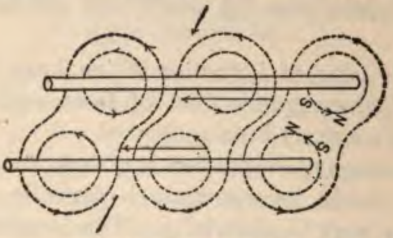

FIG. 23.—ATTRACTION OF CONDUCTORS CARRYING SIMILAR CURRENTS.

This appears as a case of unlike attracting unlike. If the attraction of the two similar currents for each other is referred to their lines of force, the phenomenon of attraction reminds us of electrostatic attraction. In the latter unlike attracts unlike. In the attraction of similar currents the attraction of unlike for unlike is found in the contiguous portions of the lines of force surrounding the two wires.

If, on the other hand, the currents in the two wires are of opposite directions, they will repel each other.

Again picturing the annular or ring-shaped lines of force, it will be seen that the contiguous portions of these lines in the case supposed will be of identical polarity, so that the phenomenon reduces itself to a case of repulsion of like by like.

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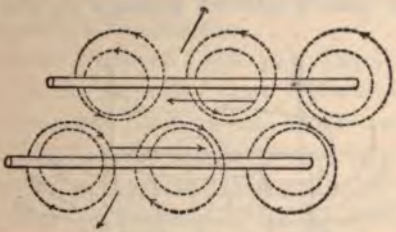

FIG. 24.—REPULSION OF CONDUCTORS CARRYING OPPOSITE CURRENTS.

Thus, the apparent exception to the rules of likes and unlikes which is presented by wires, in which like currents attract and unlike repel each other, when reduced to phenomena of lines of force disappears. The general electrostatic law applies to the lines of force surrounding current-bearing conductors. These lines appear subject to it, while the currents are not. This is as it should be, because attraction and repulsion are due to ether stress which is

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expressed in lines of force, as regards its direction and polarity. Again, we find in the repulsion of lines of force of like polarity a version of the spreading out of lines which has already been spoken of (pp. 79 and 80). In the attraction of lines of force of opposite polarity we find the reverse state of things, as might naturally have been anticipated. These are two of the fundamental phenomena of induction.

If now we take a single wire and bend it into a spiral, and pass a current through it, the annular rings will blend, and approximately elliptical ring-shaped lines of force will be produced. Resistance has been spoken of in connection with currents. It has its analogue, called reluctance, in connection with lines of force. These go more easily through

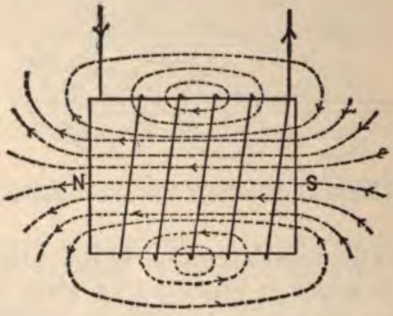

FIG. 25.—ACTIVE SPIRAL CONDUCTOR DEVELOPING LINES OF FORCE.

some substances than through others. Iron, nickel, and cobalt are good vehicles for lines of force, or have low reluctance. Other materials have higher reluctance, and vary but slightly from air as regards their degree of the same.

The coiled wire maintains a set of lines of force of rather low intensity, forming a magnetic field. If now a piece of iron is inserted in the coils, the field will be greatly intensified, because of the good vehicle for the transmission of lines of force provided in the iron. The magnetic field becomes very dense. Iron possesses low reluctance.

Electrostatic lines of force pass out into space until they meet opposite ones. Electromagnetic lines, on the other hand, always return into themselves. This gives the idea of a magnetic circuit. Every line of force of the electromagnetic kind includes the idea of a magnetic circuit closely analogous to an electric circuit.

The field of force created by coiled wires bearing currents, and strengthened in their action by an iron core, is the one used practically in dynamos and motors. This field of force is no impracticable, dry abstraction; it is at the basis of the action of every dynamo. All the electric lights and other powerful manifestations of electricity are due to the maintenance of such fields of force.

A typical magnet, with the direction of its lines of force, is shown in the diagram Fig. 14. The idea of a magnetic circuit is very clearly shown here. The analogy with an electric circuit (generator and conductor bearing a current) is so good that the most practical calculations of electromagnets are based upon laws similar to Ohm's law, and embodying exactly similar ideas.

Iron, having little reluctance, always concentrates in itself lines of force. The attraction of a magnet for its armature, or for any piece of iron, may be based upon the desire of the lines of force to take as good and short a path as possible. Their path is improved and shortened when the armature is in contact with the pole; hence the attraction of the magnet therefor.

Thus, we have examined, although superficially, two typical cases of lines and fields of force. The next step is to see how a current can be generated by the agency of such a field.

If two wires or conductors are placed close together, of which one only carries a steady current, the second wire will show not the least effect. But if the current in the other wire be varied in intensity or direction, then momentary currents will be induced in the other if its ends are joined so as to form a closed circuit.

A theory or picturing of this is easily conceived of. It seems perfectly obvious that any disturbance of the lines of force which represent ether stress, and do not represent ether motion or ether waves, will disturb the ether near them. The adjacent wire opens through the ether a path for a current. Hence the disturbance of the lines of force, involving waves of motion of the ether, establishes, as if it were by a species of sympathetic or harmonic vibration, a set of circular lines of force around the axis determined by the path through the ether opened by the other wire. But the forced establishment of these lines of force entails a current through the conductor in their axis, because lines of force and currents are so intimately connected that one cannot exist without the other, and disturbance of or creation of lines of force always affects a current. The creation of new lines of force around an idle closed-circuit conductor cannot take place without the production of a current. Lines of force proper to a conductor cannot exist without an accompanying current.

The new lines of force are only determined by the change in the primary ones, and only exist while such change is taking place. Hence an induced current is of very short duration, and a steady current can only be produced by a continuous disturbance.

A disturbance in the inducing conductor in the direction of increased strength of current gives the lines of force an extra thrust, as it were, and they tend, as if by cog-wheel action, to give the new lines of force around the neighboring wires opposite polarity. This entails a similar direction of polarization in contiguous parts, so that the two sets repel each other. This is merely another way of saying that the currents are in opposite directions, something which would follow from the opposite polarization of the lines of force.

A disturbance in the direction of decreased strength of current, by letting the polarity of its circular lines of force diminish, gives a twist in the opposite direction to the ether in contact with them. This induces lines of force around the adjoining wire of similar circular polarity. Hence, the new and old set of lines of force, having their contiguous portions of unlike polarity, attract each other, and, as the circular polarity is identical in both sets, the currents, original and induced, are in the same direction.

All this coincides with the explanations given on pages 96 and 97.

If we think of the circular lines of force in acquiring or losing intensity as being subjected to a virtual acceleration or retardation of polarization corresponding to a species of rotation, it will appear quite evident that they should thus affect the contiguous embryonic lines of force localized by a neighboring closed circuit. We have to imagine the circular lines of force as indicating the direction of a circular stress in the ether.

From a magnet's face and sides the magnetic influence or lines of force proceed in lines not very far from straight in the immediate neighborhood of the pole. If the magnetic force is constant, there are no ether waves, but only ether stress, and no current can be induced. If a wire of a closed inactive circuit is moved among these lines of force, it is subjected to ether stresses varying in intensity, which is another way of producing the effect of waves. As if by a species of friction against the lines of force of the magnetic field, the circular lines of force around the wire are developed as before, and a current is started through it. If the wire is approaching the pole, it is the same as if a wave due to intensification of current met it, and lines of force of opposite sense are produced, or an inverse current. If preceding from the pole, exactly the opposite effect is produced.

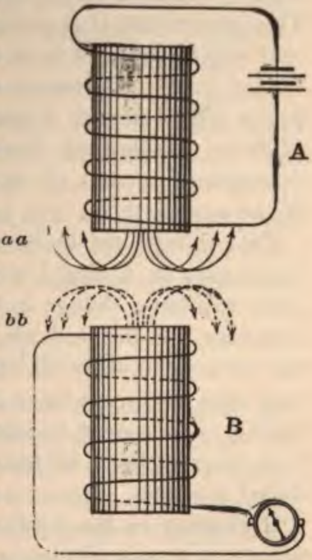

FIG. 26.—GENERATION OF A CURRENT BY INDUCTION.

Again, we may take two bobbins, one A having a steady current passing around its coils, the other B ready to receive a current. If the inductor bobbin A is approached by the bobbin B, it is clear that lines of force of the direction *a*, *a* will thrust against the ether surrounding B, and we may imagine a tendency to force new lines into the direction *b*, *b*. The currents of the windings of the bobbins, corresponding to lines of force of opposite polarity, such as shown, are obviously of opposite direction themselves. This means that if B approaches A a temporary current will be induced in its coils, of opposite direction to that in B. If drawn away, then obviously the opposite effect should follow, and does follow. Lines of force of identical direction are produced, with a consequent current of the same direction, as that of the current in A.

Two things are to be remembered: The current is induced in a closed circuit; no induction takes place without a change in the stress of the ether surrounding the induced wire. This change may take the form of a wave, or the motion of the induced wire may produce a wave effect, and give the desired thrust, or whatever it may be, that determines the formation of lines of force and of a temporary induced current.

Recurring to the bobbins A and B, they may approach in arcs or circles or in any way, but the motion may always be resolved so as to give a resultant indicating approach or recession. From this the direction of the current can be told. The law by which it is regulated is known as Lenz's law, which may be thus expressed: The induced currents are such as to develop resistance to the change brought about. Thus, approach develops an opposite current because opposite currents resist approach, while recession develops a current of similar direction because similar currents attract each other. Starting or intensifying a current produces effects corresponding to approach, and stopping or diminishing a current corresponds in effect to recession.

The direction of lines of force can be mapped out by iron filings or by a compass needle. Thus they seem to the mind to have some real existence. The reactions among themselves have to remain little more than a metaphor, and this metaphorical presentation of the subject is for the present about all that can be done to give the mind some picture of the induction of currents.

The Induction Coil and Its Application.

It is a simple matter, on the principles just described, to produce high-tension electric charges in small quantity from low-tension charges in large quantity or to do the reverse. A stick of sealing-wax rubbed against the coat sleeve may give a higher tension than an enormous dynamo. The old-fashioned frictional electric machine is based upon this principle. The trouble with the frictional machine and its successors, the influence machines, Holtz and Wimshurst types, is that they produce high-tension charges, but the current is apt to be intermittent and of very small quantity. Induction coils were designed to act as a substitute for frictional machines. They provide a comparatively constant discharge through air, and can be modified so as to give any ratio of currents and tension.

The induction coil has received most important applications recently. It is the controlling element, used in the exact reverse of its original action, in alternating-current lighting, and it has been used in another application, also the reverse of the original, for producing a current adapted for electric welding.

The action of a wire, through which an alternating current, or other current suddenly varied is passed, upon a neighboring circuit partly parallel thereto, has already been explained. The induction coil is simply an extension of this idea.

A bundle of straight iron wires laid together may be taken as the core upon which an insulated copper wire is wound. If a current is passed through this coil, it will create lines of force, which will be concentrated by virtue of the presence of the iron.

Such an arrangement is called a spark coil, and is in itself sufficient to give a high enough tension to produce a spark. If the excited circuit is suddenly opened or shut, a spark will appear at the point of "make and break." The electricity heaps itself up, as it were, and by a species of electric inertia accumulates tension enough to jump across the interval if not too large. For a fair-sized spark the conducting wire must have plenty of convolutions, and a good iron-wire core is essential. The phenomenon is attributed to self-induction, each convolution acting upon the others as if they were in independent circuits.

The sparking seen sometimes in telegraph instruments is due to the magnets acting as spark coils.

The induction coil is an extension of the simple spark coil. Around an iron core is wound an insulated copper wire provided with an arrangement, like a little hammer and anvil, or some equivalent, for very rapidly making and breaking the circuit, or for reversing and alternating the current. A battery or some other generator is in circuit with this wire, which is termed the primary.

When a current is passed through it, the iron core becomes a magnet, and attracting the hammer draws it away from the anvil and breaks the circuit. The iron core, then being no longer magnetized, releases the hammer, which falls on the anvil, and again closes the circuit, only to be reopened. This succession goes on with the highest rapidity.

Sparking is prevented to a certain extent by the use of a condenser, which is a series of sheets of tinfoil, with paper interposed between each pair. Each alternate sheet of foil is connected to one and the other terminal of the primary coil. The charge which would produce the spark on breaking, rushes into the condenser to be at once discharged in the opposite direction through the coil, now on open circuit.

It is obvious that very rapid and violent disturbances of the lines of force and consequent ether waves follow this succession of makes and breaks. The disturbances are utilized by winding a second insulated wire over the core, directly over or next to the primary. At each make and break a pulse of current goes through the secondary coil, as the other one is termed.

The primary coil in ordinary practice is made thick, with comparatively few convolutions. The secondary coil is then made of fine wire, and of a large number of convolutions, and of great length.

The tension of the electricity in the secondary depends upon the ratio of its number of turns to those of the primary, the tension increasing with such number.

This describes the general construction of the regular induction coil. There are several things essential to the perfect operation and durability of a coil. The great point is good insulation. The secondary wire shows the strongest tendency to an escape of current from one convolution to another. The method of winding the secondary is sometimes such as to prevent this, the convolutions furthest removed in potential being kept also as far removed in position as possible.

In the practical calculations employed by the engineers of the alternating-current system the circuits are calculated as varying in tension directly as the relative number of convolutions of the primary and secondary, and the currents in the inverse ratio.

If the primary wire is made very long, so as to include many convolutions as compared to the secondary, the secondary circuit will include a much lower potential difference. Thus the potential difference between the terminals where the primary current enters the coil may be one or two thousand volts, and the terminals of the secondary may only differ by fifty or a hundred volts. The ratio can be made anything. In alternate-current lighting a common reduction of potential is from one thousand volts in the primary to fifty volts in the secondary. In electric welding the reduction is many times greater than this. In both these cases there is no mechanical circuit breaker. The original current is an alternating one and acts by induction upon the secondary. The hammer and anvil or other make and break device is entirely omitted, the alternating current acting by itself. The lighting coils can be seen located on window sills and elsewhere on buildings supplied by the alternating current system of lighting. They are termed transformers.

CHAPTER VII.

THE GALVANIC BATTERY—THE ELECTROLYTE, AND THE LOCUS OF ITS POTENTIAL DIFFERENCE—POLARIZATION AND LOCAL ACTION—DIFFERENT EXAMPLES OF BATTERIES—THE ARRANGEMENT AND ACTION OF BATTERIES—STORAGE BATTERIES.

The Galvanic Battery. The Electrolyte, and the Locus of Its Potential Difference.

FROM a scientist's point of view, the electrostatic charge—that is to say, the charge held by a body—is of equal interest with the current. But as nearly all the great manifestations of electricity are due to currents, the charge is apt to be thought of as something dry and unpractical compared with the manifestations of electricity in motion or in current form. The two are related intimately, as has been shown in preceding chapters.

The oldest familiar method of producing a current is by the galvanic battery. Accepting the contact theory, we may see how it explains the action of a battery. The simplest battery consists of two plates or pieces of different conducting materials immersed in liquid which acts more upon one than upon the other. The plate most acted on is called the positive, the other the negative, one. The original Volta's element consisted of a plate of copper and a plate of zinc immersed in dilute sulphuric acid. Unless special features are introduced or superadded, it is a very poor and inefficient battery. Yet it was with such an appliance that Sir Humphrey Davy performed his classic experiments upon the metals of the alkalies and produced the first voltaic arc.

His battery had impure zincs and yielded large amounts of ill-smelling gas. From the first instant of immersion the bubbling and effervescing cups of dilute acid began to lose strength, and in half an hour probably were nearly exhausted, whether in use or disconnected. A modern battery would hold its strength for a long time if not used, and if doing work would not soon become exhausted. Sir Humphrey Davy never worked with an appliance relatively poorer than the great battery of the Royal Institution. It must have required very active work to immerse its many hundred plates, and get any results from it before its strength was expended.

There are a great variety of batteries. The purpose of these chapters will be best subserved by first taking into consideration a battery in which an acid, which may be dilute sulphuric acid, is the exciting liquid, and zinc, as in ninety-nine out of a hundred batteries, is the material of the positive plate.

If the zinc is chemically pure, or if it is amalgamated or alloyed with mercury, and if it is not in contract with the other plate no action that is visible takes place. But if the plates are tested for charge, the zinc will be found to be of different potential than the copper. It follows that if in any way a discharge is effected, there will be thereby produced a brief current. This can be done by bringing the plates into metallic contact. But on effecting this, which is usually done by connecting the ends of a wire to each plate, the discharge will not be instantaneous only, but will be continuous; in other words, a current will result. If elements enough in number and large enough are used, any conceivable current may be produced. It will produce the voltaic arc, or will melt the most infusible metals if they are made part of the metallic conductor or wire. Therefore a constant system of charging must take place.

If the simple Volta combination is used, an effervescence, or escape of gas bubbles, from the surface of the negative plate will be observed. On collecting and examining these bubbles, they are found to be composed of the gas, hydrogen. No action is discernible at the positive plate of amalgamated zinc except a gradual diminution in weight and size. Theory can be applied to the battery action to explain what is taking place.

The chemist on examining the battery finds that water is being decomposed. The oxygen of the water acts upon the zinc and oxidizes it, forming zinc oxide, which dissolves in the acid, causing the production of zinc sulphate and wasting of the plate. The hydrogen of the water goes to the copper and escapes from its surface as the bubbles already mentioned. Hence the battery is pulling apart oxygen and hydrogen, which have been in the most intimate contact, namely, in chemical or atomic combination. As the two are torn apart by the superior affinity of the zinc for the oxygen, they come off oppositely charged with electricities, or differing in potential one from the other. This tearing apart of the two elements is continuously taking place as long as the plates are in metallic contact, so that a continuous discharge through the wire is effected or a current results.

Water acidulated with sulphuric acid is a conductor. It might therefore seem to follow that the plates should discharge through the liquid of the element when the wire connection is not maintained. But the affinity of the zinc for oxygen, involving the holding of the water molecules in unstable equilibrium, maintains a difference of potential in spite of the watery conductor between. It so totally changes the conditions that no current whatever passes through the acid to discharge the plates, and, as far as any current may be supposed to go through the liquid, it is in the nature of a charging current. The liquid, while a true conductor and capable of acting as such under proper conditions, becomes an electrolyte in the battery and loses its power of simply conducting a current.

It is not necessary to adopt the contact theory, which is now rejected by many authorities. We may assume that different elements carry individual and invariable quantities of electric charge. The zinc attracts the oxygen atoms, combines with them, thus setting free their charge, to be taken up by the surface of the zinc or positive plate. In an instant it becomes so highly charged that it repels the other atoms of oxygen. When the wire is connected it carries off this charge to the copper, and the zinc, being discharged, is restored to a condition to attract more oxygen.

The well-known diagram illustrates the action of the zinc and copper on the liquid in the battery. The oxygen keeps disappearing by combination with the zinc at one end of the battery; the hydrogen, by evolution as a gas, disappears at the other. At the same time the molecules keep exchanging atoms so that a constant travelling of the atoms from end to end of the liquid is kept up. In this way what is virtually a current goes through the water. It is perhaps, no current, properly speaking, the liquid simply effecting the continuous charging of the zinc with electricity opposite to that of the copper.

Such a liquid is called an electrolyte, and this decomposition, which is exactly proportional to the current produced, is due to electrolytic conduction.

Water, then, if not absolutely pure, can conduct electricity either as a regular conductor or electrolytically. A current may be caused to pass through it by immersing in a vessel of the fluid two terminals or conductors coming from a battery or other source of electricity. If the difference of potential between the terminals is high enough, the water will be decomposed and will give off oxygen to one terminal and hydrogen to the other. The travel of the atoms in both directions takes place, and the water acts as an electrolyte. Whether a current goes through it

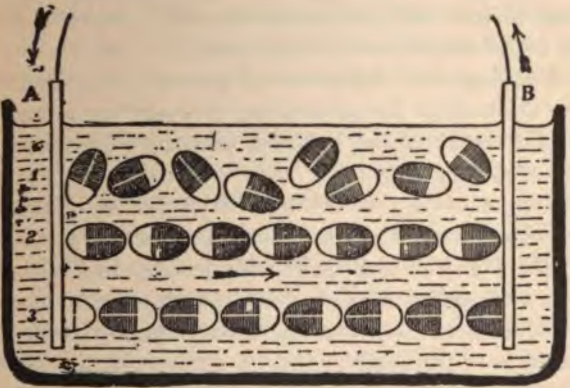

FIG. 27.

or not, we have seen to be problematical. It is enough to believe that the oxygen atoms carry off the electricity opposite to their own, and that the hydrogen atoms do the same for the reverse quality of electricity. If the difference of potential, on the other hand, between the two immersed terminals is low enough, no decomposition will take place, and a true current will go through the fluid, which acts as an actual conductor in such a case.

The degree of difference of potential required for the electrolytic decomposition of every compound is absolutely fixed, and has been determined for a number of substances.

The knowledge of this quantity tells the difference of potential which the combination of the elements of these same compounds will develop in a battery. The potential difference required to effect a decomposition is the same as that developed by the combination of the same elements. The potential difference is also precisely related to the heat produced by the same combination or to the heat required to effect the same decomposition.

The difference of potential maintained between the opposite elements of a battery is generally referred to its terminals or binding screws. It really should be sought at the active surfaces of the plates. The terminals may be at a determinably lower potential difference than the surface of the plates, although in almost all cases the difference is so slight as not to be measurable.

Polarization and Local Action. Different Examples of Batteries.

If the plates of a Volta's battery are connected by a wire, a current will go through it. But the current will very quickly weaken and in a few minutes will be so slight as to be almost useless for practical purposes. The battery is said to be polarized. Polarization was the great trouble scientists of the days of Davy had to contend with in their batteries.

Polarization in the electrical world is made to cover a multitude of sins. Properly it denotes interference, due to internal causes, with the proper action of a battery. In the case of the Volta's element the oxygen goes to the zinc and delivers its charge of electricity thereto and combines with it, to be dissolved on combining with the sulphuric acid radical. This leaves a fresh surface of zinc, so that there is no polarization there. If there were no acid in the water, then the surface of the zinc would become oxidized and would be no more attacked. This would be polarization, which is prevented by the acid. If we go to the other side of the battery we find the hydrogen collecting on the copper plate in minute bubbles and presently escaping therefrom and creating an effervescence in that portion of the liquid, the copper remaining coated with these bubbles. It is thus insulated from the electrolyte, the resistance of the battery is enormously increased, and it is polarized.

Another interference is produced by the hydrogen having a high affinity for oxygen. Instead of a copper-zinc couple we have to a certain extent a hydrogen-zinc couple. The latter is of far lower electromotive force.

This hydrogen polarization is dealt with in various ways. In the Smee battery, which is a modification of the Volta battery, the hydrogen is given mechanical aid to escape. The negative plate is made of silver, coated with minutely divided platinum. The escape of a gas from a liquid is greatly facilitated by the presence of finely divided material. It seems to seek for points whence to start upon its upward journey. The platinized surface of the silver enables the hydrogen to rapidly escape from the surface of the plate.

In other batteries the same object is effected, also in a mechanical way, by agitating the solution or by constantly moving the negative plates. Sometimes air is blown through the solution which carries off the hydrogen.

The chemical way of absorbing the hydrogen is more often employed. It consists in surrounding the negative plate with a solid or a liquid which combines chemically with the hydrogen. Such a liquid is dilute nitric acid, or a solution of chromic acid, of acidified potassium bichromate, or of acidified potassium permanganate. In Grove's battery the negative element is platinum surrounded by dilute nitric acid as a depolarizer. In Bunsen's battery it is a piece of carbon in a depolarizing solution of sulphuric acid and potassium bichromate.

In both these batteries it is an object to keep the hydrogen-absorbing or depolarizing liquid away from the zinc. At the same time the continuity of the liquid must be preserved or it will cease to act as an electrolyte. A cup or receptacle of porous material, such as earthenware, unglazed china, or even a parchment-paper bag, is used for this separation of liquids. The porous cup is placed within a glass one of considerably larger size, thus giving two compartments. In one is placed the negative plate with its depolarizing solution; in the other the positive plate with the dilute acid.

It will be evident that this is a very imperfect way of separating liquids. Diffusion inevitably goes on through the porous walls, but up to the present time it is about the best solution of the trouble. Electrolytic action is itself a species of diffusion.

While diffusion of the electrolyte is thus a necessity, diffusion of the depolarizer is a defect. The latter trouble could be and is sometimes prevented by the use of a solid depolarizer. But the chemical action of a solid is so sluggish that batteries of this type, while they will eventually depolarize themselves for large quantities of electricity, quickly polarize when in action. They need periodical rest to recover their energy. Such are called open-circuit batteries, as being only suited for work on lines kept open or disconnected for most of the time.

Leaving the hydrogen-producing battery, we may examine another combination incapable of this species of polarization.

If the negative plate or electrode were hydrogen, it is obvious that there would be no hydrogen polarization. The Daniell battery uses a solution which instead of hydrogen deposits copper upon a copper negative plate, and hence it is free from hydrogen polarization. It contains a copper negative and a zinc positive plate. The copper plate is immersed in a solution of copper sulphate, the zinc in a solution of zinc sulphate. A porous cup is used to separate the two liquids. Under the action of the current the copper sulphate is decomposed. The copper is deposited upon the copper plate, merely increasing its thickness, but not altering in any way its electrical position. The sulphuric acid radical combines with the zinc. In some copper sulphate batteries the porous cup is not employed, and the different specific gravity of the solutions is relied on to keep them separate (gravity battery).

In the Daniell combination is found a good illustration of injurious local action. If the battery is left with the connection between the plates broken, or on open circuit, the copper sulphate diffuses through the rest of the liquid, and attacks the zinc, dissolving it and depositing metallic copper upon it. This action is injurious as it wastes zinc and copper sulphate, and even tends to produce a species of polarization.

The Volta and Smee batteries are examples of single-fluid combinations, the others of two-fluid combinations.

Sometimes, as has been said, solid depolarizers are employed. Thus in the Leclanché battery binoxide of manganese is the agent for disposing of the hydrogen. The porous cup contains a carbon plate surrounded by a mixture of carbon in powder and of binoxide of manganese. The latter is reduced to sesquioxide by the hydrogen. The Leclanché battery is extensively used on "open-circuit work," in the telephone service and for bell-ringing.

Other causes operate to impair the power of batteries. One is poor diffusion. The liquid directly between the plates is acted on more strongly in the electrolytic way than any of the rest. Hence it is the first to be exhausted, and diffusion from the rest of the vessel has to replace it. This takes place rather slowly. Agitation of the liquid by mechanical means helps diffusion. The blowing air through the liquid, already mentioned, acts to facilitate diffusion as well as to remove hydrogen

Some batteries are constructed with a view to prevent diffusion so as to avoid local action. A jelly is often used to retain the electrolyte. Such are called dry batteries, and are adapted only for open-circuit work.

The Arrangement and Action of Batteries.

A cup of acid, with a plate of zinc and one of copper immersed in it, as we have seen, forms a battery. The ends of the plates projecting from the liquid are connected to the wire through which the current is to go. The current thus given is comparatively weak. It may be increased by connecting more cups together.

The exact function of a single couple should be clearly understood. It maintains a specific difference of potential between the surfaces of its two plates or, what is the same thing, between the ends of the wire connected to the battery terminals. It also introduces a specific resistance which depends upon the nature of the solution and varies in amount inversely with the facing areas of the plates and with their distance apart. Yet attempts to calculate this resistance by the specific conductivity of the solution are not practically successful.

Having a number of cells at our disposal we can halve the resistance of a single cell, without change of potential, by combining the two cells in parallel. This is done by connecting both negative plates together, as well as both positive. This gives us what is virtually a single cell of a battery, having the same electromotive force or potential difference, but only one-half the resistance of a single cell. A third cup can be connected in parallel with the other two, which will give one-third the original resistance, with the same potential difference, and so on.

If, on the other hand, it is the electromotive force that is to be increased, the cells must be connected in series. This is done by connecting the copper or carbon of one cell to the zinc of the other, the ends of the live wire or main conductor connecting one with the final negative, the other with the final positive, plate. Two cells thus arranged will produce double the difference of potential, but at the same time will give double the resistance.

The two systems may be combined in one battery. Thus, one pair in series may be placed in parallel with another pair also in series. To do this, two negative and two positive plates are connected right through, requiring four cells. This gives the resistance of a single cell and the electromotive force of two cells.

The full investigation of the arrangement and number of cells for different purposes belongs to the subject of electrical calculations. It is enough to understand the *rôle* of the battery in general. It maintains a difference of potential between its opposite poles, and introduces the hurtful element of its own resistance into the circuit. From this some curious conditions arise. If the minimum number of cells for a given current are required, the resistance of the cells must equal that of the external circuit. Suppose next that there are a number of cells placed in series but connected by a short, thick wire of practically no resistance. Any number of cells may be added in series to those already there without giving any more current ; because as fast as the difference of potential increases, so does the resistance in the same ratio.

If, on the other hand, the external circuit is very long or of high resistance, and the cells of the battery are arranged in parallel, any number may be added in parallel and the current will be increased only by a very minute amount. What is wanted in this case is higher electromotive force. The cells should be arranged in series.

In either case the maximum current would be given by having the resistance of the battery equal to that of the line. The cells were arranged to the worst advantage possible in both supposed cases.

We have seen in chapter IV. that electric work is measured in volt-amperes, or, if we follow out Ohm's law, is proportional to the square of the current multiplied by the resistance. This is deduced by algebraic transformation of the original equation. From this proposition it follows that a battery does work in sending a current through a resistance. This resistance includes the entire circuit, battery and all. It follows also that any portion of the circuit receives a quantity of work proportional to its resistance. This is because in a single circuit precisely the same current goes through every part of it at the same time. As only the resistance varies, the work expended on any part of the circuit is proportional to the square of the resistance.

The fact that the current is the same in all parts of a circuit, although obvious enough, has more than once escaped apprehension by workers in electricity. Where a number of electromagnets are arranged in series on a circuit, as in automatic telegraph systems, to have them work evenly their resistance need not be equal. The number of convolutions must be the same, irrespective of resistance; yet it is on record that the error of supposing that the resistance was the controlling factor was committed by a professional electrician.

The circuit is composed of the wire or other conductor connecting the extremities of the battery, and of the battery itself. The current is generally, for convenience or as a matter of course, assumed to go through the battery. The battery in reality is working as an electrolytic conductor, its resistance may be termed an electrolytic resistance, and cannot in practice be calculated with any accuracy as an ordinary resistance. The battery expends its energy on maintaining a difference of potential at its extremities against the constant draught made upon this potential by the current. This difference causes a current to go through the wire. Meanwhile in all the battery cups the atomic migration of oxygen to zinc or positive plate and of hydrogen to carbon or negative plate, or some corresponding action according to the battery, is taking place. This amounts to a continuous resupplying of the charge taken from the positive to the negative plate by the wire of the external circuit. This travel of the atoms is as if a quantity of infinitely small receptacles of electricity were pouring out their contents into the plates of the battery.

This conception, it will be seen, brings out the theory of electrolytic conduction by excluding the existence of a current properly so called within the battery, the battery acting as a replenisher of the electricity exhausted from the terminals of the battery by the wire connecting them. At the same time the atoms travel more or less easily according to the space they have to travel over and according to the cross-sectional area of their path. This variation in ease of travel constitutes the variation in resistance of the battery.

Given quantities of oxygen and hydrogen always deliver equal quantities of electricity to their respective poles. The conditions may be such that a higher or lower difference of potential is established and maintained at the terminals, but the current is exactly proportional to the oxygen consumed by the zinc or zinc consumed by the oxygen, according to the way we look at it, and the same for the other constituents.

Thus, in a copper-sulphate battery (Daniell's, Gravity, etc.), if we weigh the copper plates before it goes to work and then take a current from it, we can determine what quantity of electricity its current delivered by weighing the same plates at the conclusion of the time of action. Their increase of weight will be exactly proportional to the quantity delivered by the current, or to the coulombs or other unit of quantity. In like manner the zincs might be weighed, and their loss of weight would be proportional to the same thing. The copper sulphate expended might be determined with the same result.

It must be understood that each quantity would be different, but that the quantity of each constituent would be proportional to the current in its own particular ratio.

Again, from another combination the same quantity of coulombs might be taken at nearly double the potential; yet the same quantity of zinc would be dissolved, notwithstanding the higher potential of the battery terminals. Consumption of chemicals corresponds to coulombs of electricity; difference of potential corresponds to relative chemical affinities.

The law of electrolytes, as explained under the subject of the chemistry of the current, applies accurately to the plates and solution of the electric battery itself. If the current from a battery decomposes a given amount of an electrolyte in a separate vessel, the decompositions in the battery itself will be exactly in the proper ratio, depending on the atomic weights and valencies of the elements decomposed in the battery and in the electrolytic cell.

Storage Batteries.

An ordinary battery consists of a positive element attacked by the active solution, of a negative element unattacked thereby, and of some kind of depolarizer. The constituent parts are procured ready made from the chemical factory, zinc works, etc., and are introduced with water into the cups, and the battery is said to be set up. In use it runs down, the positive plate dissolves, the active solution and the depolarizer become exhausted, and after a while it has to be recharged. The old spent solutions are generally thrown away.

If for the ordinary type of positive plates or element and for the depolarizer we substitute materials which can be produced in a cell by a galvanic current, namely, by electrolysis or electroplating, we have a storage or secondary battery. Where an ordinary battery is emptied and recharged, a storage battery is simply treated by passing through it a current in the direction opposite to that of its own natural current. After it has been exposed to the current it becomes electrolyzed. Upon one plate there may be deposited or formed the depolarizer, upon the other the positive material is formed and the exhausted solution in doing this is decomposed and restored to an active condition. When the charging current is stopped, and the battery is put to work, it delivers a current in a reverse direction to that of the charging current, and in doing so it gradually undoes the work which has been expended upon it. When its power runs down, it is again recharged and is again ready for work.

This is the general mode of action of storage batteries. The favorite type is the lead-sulphuric acid-lead binoxide type. These consist of leaden plates for the elements. One set of plates, the negative ones, is charged with lead binoxide as a depolarizer, the other set with finely divided metallic lead as the positive element, and the solution is dilute sulphuric acid.

The action is not yet perfectly settled, but in general is as follows: The spongy lead of the positive plates, when the current passes, is converted into lead sulphate. The hydrogen which goes to the negative plate is oxidized into water at the expense of the oxygen of the lead binoxide, and a difference of potential is thus established, which is used to produce a current.

It will be noted that no current would be produced by two plates of lead. The depolarizer or film of lead binoxide must be considered both negative plate and depolarizer.

When the charging current is passed through the solution, another action possibly comes in to re-enforce the above charging process. The negative plate may absorb and retain directly oxygen, and the positive plate may do the same for an equivalent quantity of hydrogen. Then in the use of the cell the hydrogen is consumed and the oxygen acts as a depolarizer.

Grove's gas battery illustrates this last process perfectly. It consists of plates of platinum immersed in pairs in cups of dilute sulphuric acid and connected alternately like the regular plates of a battery. Of course no current passes when the circuit is closed. But if a current is passed through the solution with the plates as electrodes, and due to a sufficient potential difference to decompose the water in the cells or cups, hydrogen accumulates on and in one electrode and oxygen on the other. On stopping the charging current, the battery is ready for action, and when connected a reverse current will be yielded by it. The hydrogen is the positive element, the oxygen is the depolarizer, and the platinum is the negative element.

In point of time Grove's gas battery, which is a typical secondary battery, antedates all the present storage batteries, and was devised years before the name of storage or secondary battery was even thought of, and before any capitalist investigated the profits involved in the "storage of electricity."

Secondary batteries, it will be seen, are merely contrivances which substitute electrical for manual regeneration or recharging of their cells. Their success, as far as attained, is due to one circumstance—their possession of very low resistance. A primary battery cannot be made of as low resistance within the same compass.

Their weight still is too great and militates strongly against them. The heavy leaden plates are but massive skeletons for the support of very small portions of active material. While many other arrangements have been tried, at the present time the regular lead-plate combination is most used.

The following figures are of interest in this connection.

When energy is stored up in bent steel springs, about forty kilograms can be lifted one metre by the elasticity of a spring weighing one kilogram.

When it is stored up in air compressed to one-sixth of its volume, about four hundred and sixty kilograms can be lifted in practice, one metre by one kilogram of air.

When it is stored in storage batteries, about 3,370 kilograms can be raised one metre by one kilogram weight of battery. (Abridged from Daniell's "Physics.")

This gives a ratio per unit weight in the three cases of 40 : 460 : 3370 or of 10 : 115 : 842 about, showing that there is room for improvement in diminishing the weight of the storage battery.

CHAPTER VIII.

DYNAMOS—MOTORS—TRANSMISSION OF POWER.

Dynamos.

NOTHING in electric practice looks stranger to one unaccustomed to it than to see a whirling mass of wire, in contact with nothing but its bearings and the commutator brushes, act as the generator of a current that can illuminate a whole district of a city or do the heaviest kinds of electric work. The illustration of induction given in a preceding portion of this work contains the germ of a dynamo's action in a crude analogy.

Suppose two electromagnets, one excited and the other passive, to be mounted face to face, one being arranged with mechanism so as to be quickly slid back and forth, toward and away from the other. If the stationary, or field magnet as it would be called, were kept excited by an independent current, and if the circuit of the other unexcited magnet were closed, then currents would be induced in the inactive magnet as already explained, first in one direction and then in the other. The contrivance would be an alternating-current dynamo.

While the current in the coils of the moving magnet would inevitably change in direction according to the way it was moving, whether toward or away from the stationary or field magnet, it is easy to imagine some subsidiary mechanism that would connect alternately the ends of the outer circuit to opposite ends of the winding of the moving magnet—in one way when approaching, in the other way when receding from, the field magnet. This would give pulses constant in direction but of varying intensity. The subsidiary mechanism is called a commutator. This arrangement would be a constant-direction-current dynamo.

Another thing is obvious—that the outer circuit might include within it the winding or coils of the field magnet, so that the mechanism would produce a current without external aid. It would then be a self-exciting dynamo.

Very rapid motion is essential to strong induction by the means described. It would be far easier to secure this by whirling the moving electromagnet around in front of the other than by reciprocating it. In practice rotation is invariably used.

The moving coil of wire has to be wound upon a core of iron to entitle it to be called an electromagnet. The correct name for it is the armature. The purpose of the iron core is to concentrate the lines of force so as to give what is known as an intense field, and also for another reason: the iron core of the armature forms part of the magnetic circuit, and to avoid the expenditure of more energy than is requisite in maintaining lines of force through the circuit the reluctance of the circuit must be as low as possible.

Of course a permanent magnet could be used as the field. In such case no energy would be expended on its excitation, and the last remark would not apply so fully. Even in this case the lower the reluctance the better is the design.

A rotating armature, a commutator, and a field magnet or magnets, called the field for brevity, are the three essentials of a constant-direction-current dynamo. If the commutator is dispensed with, and a simple collector of any kind is used in its place, the three elements become substantially two, and we have an alternating-current dynamo. In these the field is usually excited by a separate source of current.

Upon the shape and proportions of field, and of armature, and methods of winding, endless variations have been rung by different inventors. Generally the lines have settled down into a few typical forms. In practice these have to be varied to secure proper currents and proper potential difference at the terminals of the dynamo, all of which is the subject of mathematical calculation.

It may be asked how a self-exciting dynamo is started. Iron that has once been magnetized always retains some of its mangetism. The fields of a dynamo are always a little excited with residual magnetism, so that when the armature begins to rotate a slight current is at once induced in it. This strengthens the field, and the stronger field reacts in turn to increase the current, so that the normal strength is soon attained.

Ordinary direct-current electric-lighting dynamos give from one hundred and twenty-five to one hundred and fifty volts potential difference between their terminals. But this is far exceeded in alternating-current lighting. In this country an average potential difference is one thousand volts. In London this has been also exceeded. The great Ferranti dynamos at the Deptford central lighting station maintain an average potential difference exceeding ten thousand volts. Each of these gigantic machines is of ten thousand horse-power. The armature core is in the shape of a ring thirty-five feet in diameter, and weighing with its shaft two hundred and twenty-five tons. The field magnets weigh three hundred and fifty tons. To the armature shaft are connected two 5,000 horse-power steam engines, one at each end of the shaft. The whole installation is the most colossal piece of electrical engineering ever erected.

Motors.

In describing a dynamo the armature has been spoken of as an electromagnet. If a current from an external source is passed into a constant-direction-current dynamo, it will excite the armature so as to make it a magnet in reality, and will also excite the fields. The current will enter at the terminals of the machine and will pass through the commutator into the armature. The relation of parts is such that in doing this it will devélop north and south poles in parts of the periphery of the armature distant from the north and south poles of the fields. As like poles repel and unlike attract each other, the armature will at once turn a little to satisfy both the attraction and repulsion. But as soon as it has turned a short distance the action of the commutator shifts the current, and new poles are established in the armature back of the first and in the same relative positions which they at first occupied. The armature continues to rotate as the new poles are attracted and repelled, and after a few degrees of turn the commutator again acts as before, and shifts the poles back a little. This action goes on and the armature continues rotating as long as current is supplied.

It is evident that if there were no commutator, and if the armature had fixed poles, it never could rotate through a greater angle than one of 180°.

The discovery that a dynamo is also a motor, or the discovery of the reversibility of the dynamo, is considered one of high importance. A dynamo is an apparatus for converting mechanical into electric energy. If electric energy is supplied, it can then convert that into mechanical energy.

The reciprocating and utterly impracticable type of dynamo was used as an illustration of the principles involved in these mechanisms. It is impracticable because of the low speed with which it can be moved. But this objection does not apply to motors. A low-speed motor is very desirable, and the original motors were constructed on reciprocating lines.

This reversibility of the dynamo brings about some curious results. If an electric railway is arranged with the motors on its different cars in series, rather an unusual arrangement, then, when a car is running down hill, its motor, instead of driving the car, is driven by it and becomes a dynamo, and sends current into the line. This helps to drive the other cars; so that it is quite conceivable that on a line many miles might intervene between two cars, yet one running down a steep hill would pull the other one along the line and help to pull it up a distant hill.

When a dynamo is generating current it absorbs mechanical energy. Hence the electric car in running down the hill and generating electrical energy has the mechanical energy due to its descent absorbed by the motor acting as a dynamo, so that a brake action is produced retarding the speed of descent.

Thus two cars distant from each other may be as effectually connected in their movements by a slender, motionless wire as if they were attached to a traction cable.

Transmission of Power.

The transmission of power depends on the principles enunciated especially in the preceding pages on batteries, dynamos, and motors. The transmission of power by electricity involves: (1) A source of electric energy, generally a steam engine or waterwheel and dynamo, sometimes a battery; (2) a line of wire to act as conductor; and (3) a motor. These parts being given, the method is obvious. The dynamo generates electric energy, which appears in the current-potential form, and the current flows through the conductor. It reaches the motor, which may be many miles away, and causes it to rotate. From the motor, by any of the ordinary mechanical appliances, power is communicated to machinery. The approved way of effecting the connections is to use two wires, one for the current of one direction, the other for the current of the other direction.

By means of the lines thus connecting the source of electric energy and the motor, electric energy is transmitted at any desired rate compatible with the size of the wire and the admissible potential difference or the current required. The rate of energy expended in a circuit and portion thereof is proportional to the maximum difference of potential within the limits multiplied by the current rate. If, therefore, the generator produces a high potential difference, less current will be required to give a specified product of potential difference and current rate; which is the same thing as to give a specified rate of transmission of power. But the smaller current will heat a wire less; therefore, the wire which can be used for transmission of a specified power may be made smaller as the motor works at a higher difference of potential. The size of the wire depends entirely on the current to be transmitted, and has nothing to do with the potential difference maintained at the ends of the wire considered by itself.

Thus the entire energy of Niagara Falls could be transmitted through a common telegraph wire, except that the enormous differences of potential involved would make the current escape by every possible avenue of leakage, and would make the system a menace to every one near it. The wire, however, as regards heating, would be unaffected.

At the present time electric railroads are the most familiar examples of transmission of electric energy. In the usual style of electric tramway the dynamos at the station generate electric energy. One of the wires from the dynamo goes generally to earth. The other connects with the line, called colloquially the trolley wire, that runs along the road. Each car carries a motor, one of whose terminals connects with the trolley, and the other with the earth through the wheels and rails. The current from the dynamo follows the trolley wire, enters the car motor by the trolley, and, after passing through it, goes to earth.

The cars on electric railroads are usually worked in parallel. If the line of wire and the earth beneath it be figured as two parallel conductors, the car motors are connected across from one to the other like the rungs of a ladder. The wire is made of such size as to have low resistance, keeping the potential difference between all parts of it and earth as nearly as possible the same, whether several cars are drawing upon it or not, and irrespective of whatever distance may intervene between the respective cars and the central or power station.

Cars are also worked on complete metallic circuit and in series, as already alluded to. They have attained a far more extended application in this country than elsewhere.

CHAPTER IX.

THE TELEPHONE AND MICROPHONE — ELECTRIC LIGHTING — THE ELECTRIC TELEGRAPH — THE DANGERS OF ELECTRICITY—CONDITIONS FOR RECEIVING A FATAL SHOCK.

The Telephone and Microphone.

A TELEPHONE may be considered a miniature motor and current generator, with a permanent field magnet. It is the simplest contrivance imaginable although productive of such astonishing results. It consists of a magnet N S in a handle, around whose end a fine insulated wire H is wound, and close to one of whose poles, the one nearest the coil of wire, a plate of iron D is placed. If a momentary current is sent through the wire, the strength of the magnet is altered; it may be increased or decreased according to the direction of the current through the wire. This alteration suddenly changes the attraction acting upon the iron plate, with the production of a noise due to the sudden change of pull upon and slight consequent motion of the plate. In this phase of its work the telephone represents a motor.

The telephone also can act as a dynamo or as a generator of current. This it does when spoken into and used as a transmitter. If the plate is moved suddenly the lines of force are affected and a current in one or the other direction is sent through the wire, assuming it to be on closed circuit. If two telephones are connected, and one of them is spoken into, its diaphragm, as the iron plate is called, is disturbed and a great number of pulses of current are produced. These act upon the other telephone and cause its diaphragm to repeat the vibrations of the other one. But this involves the production of sound, and of the same sound which originally produced the disturbance; in other words, the telephone "speaks."

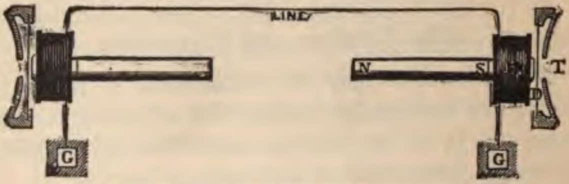

FIG. 28.—TELEPHONES AND LINE WITH EARTH CONNECTIONS.

In this, which is the simplest possible arrangement, the telephone which is spoken into is termed the transmitter, the other is the receiver. These *rôles* are interchangable. The diaphragm is made of ferrotype plate, the same material on which ferrotype or "tin type" photographs are taken.

The trouble with the arangement is the weakness of the actuating currents. This trouble is avoided by the use of the microphone, also a contrivance of the utmost simplicity, but one which is incomplete in itself, as it can do nothing without a telephone and a battery or other generator. The interest of the pair of connected telephones is that they are complete in themselves and are reversible. Either one can be transmitter or receiver in turn, which means generator and motor.

To arrange a microphone circuit, one may place in circuit a battery, two blocks of carbon, such as the lead of lead pencils is made of, and a telephone. The two blocks of carbon must rest one on the other so as to form a very loose and easily disturbed contact. It is clear that every change in the nature of this contact will change the intensity of the current. If the blocks or the table they rest on is disturbed, even by being spoken at, the disturbances will produce minute changes in the current which will reproduce the disturbances and corresponding sounds in the telephone diaphragm.

Of all substances carbon seems the best for the loose microphone contact, and is universally used. A great variety of microphones have been invented, almost all depending on loose carbon contacts. A simple form is shown in the illustration. In it C C are blocks of carbon between which a spindle of carbon A is sustained in very loose contact. The base

D serves to support the instrument. X Y are the ends of the line wires.

The mouthpiece in the ordinary telephone into which the transmitter of a message speaks is the front of a microphone. The instrument held to the ear is a simple telephone. The handle turned to ring up the central office and the other subscriber actuates a small magneto-electric generator, which rings the bell, calls up the operator at the central office, and, when contact is made, rings the bell at the receiver's instrument.

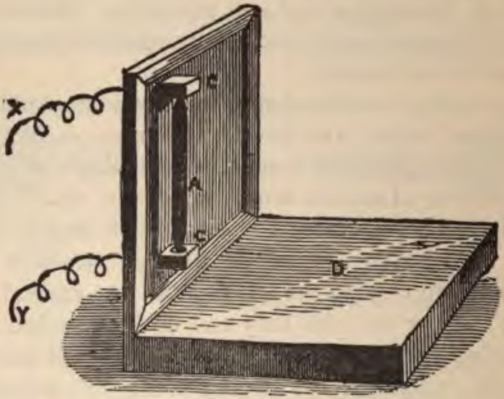

FIG. 29.—MICROPHONE.

The whole telephone system, it will be observed, represents one phase of the transmission of power.

Electric Lighting.

When a current goes through a conductor, it heats it. The degree of heating depends on the resistance offered to the current and on the current's intensity. A given current will heat a conductor of small section to a high degree, while a large conductor will carry the same current without much rise in temperature. On this principle is based the incandescent electric light. The lamp consists of an exhausted glass globe, containing a filament of carbon of high resistance. The electric-light station, by means of wire of comparatively large section, communicates with the terminals of the filament. The current heats the filament to white heat, while the wire leads are almost unaffected.

The lamps in the Edison and in most other house systems are arranged in parallel. This means that they are arranged between the leads, so that in a diagram they would represent the rungs of a ladder of which the leads would represent the sides. The electric station maintains a constant difference of potential between the leads, and the lamps are constructed to work with that difference.

In some cases, as for street lighting, the lamps are arranged in series so that the current goes consecutively through perhaps twenty, one following the other. Some device has then to be provided so that, if a lamp is broken or its filament fails, a by-pass or shunt for the current shall be provided to keep the other lamps supplied, otherwise the extinction of one would mean the extinction of all. This objectionable feature is not found in the system of parallel connection.

Sir Humphrey Davy, in 1801, working with the great (for those days) battery of the Royal Institution, found that on slightly separating the ends of a severed electric conductor the current seemed to spring across the space. He employed pieces of charcoal as terminals. These became intensely heated, and the electric arc light for the first time shone upon the world. The battery contained 2,000 plates.

This, in a few words, is the principle of the arc light now so extensively used for street lighting. By mechanism worked by the current two carbon rods are kept at an almost invariable distance apart, $\frac{1}{32}$ to $\frac{3}{32}$ inch, while the current is passing. If none passes they come in contact. This gives the conditions for an electric arc, which forms with attendant production of great heat and light. The carbons being poor conductors of heat, the effect of the arc is concentrated near their ends, intensifying the light.

Many variations of these two different methods of producing light by the current have been devised, and many modifications are in use. All the forms of electric light now in use belong distinctively to one or the other division. Those occupying a middle ground have not been extensively adopted.

The success of the electric light of the day is due to the cheap generation of electricity by the dynamo.

The alternating-current system depends upon the principle of the induction coil already explained. Alternating current is supplied from the central station through two leads, which are maintained at a high difference of potential. At points where lighting is to be done, induction coils are placed whose primaries, wound with many coils of fine wire, connect the two leads. The secondaries of the coils are of fewer convolutions and of coarser wire, and to the latter the lamps are connected in parallel.

The operation is simple. The alternating current passing through the primary induces in the secondary a current of much greater amperage, but excites a much lower difference of potential in the terminals of the secondary.

The induction coils, termed transformers, may lower the potential from one thousand volts between the terminals of the primary to fifty volts between the terminals of the secondary. This is a frequent type of reduction, but in the London installation the reduction is many times greater than this. The converters are seen attached to the outside of houses near windows, or to electric-line poles. They vary in shape and details of construction, but the principle is outlined above.

The Electric Telegraph.

The modifications of telegraphs have been endless, but in this country at the present day, the Morse system is universally used. The elements necessary are: a battery or generator, a key to make and break the current for the person transmitting, and an electromagnet with armature to act as a sounder for the person receiving the message. The armature is drawn back from the magnet by a spring. The key, battery, and magnet are arranged in circuit. If the key is depressed, the circuit is closed and the armature is attracted, giving a click. When the key is released the armature is jerked back, giving another click.

An alphabet has been devised based upon long and short depressions of the key, the famous dot and line alphabet, which enables the receiver of a message to spell out the message, by the ear, from the sound of the clicks.

In a complete system each operator needs a key and a sounder.

The Morse relay is what has made the success of the system. This is a magnet with armature, so arranged that when the armature is depressed it closes a local circuit only a few feet long, which includes a strong battery and a sounder. Thus an exceedingly weak current, which will barely work the relay magnet and will give very little sound, will operate the local circuit, producing a powerful sound from the sounder actuated by the local battery

One of the curiosities of telegraphy is that the Morse system, now almost universally used by ear, was originally devised to print a message in lines and dots. A long strip of paper was drawn by clockwork through the receiving instrument, whose armature carried a stylus or writing point which was over or under and nearly in contact with the strip of paper passing through it. When the armature was attracted, and as long as held attracted, a mark was made on the paper. By manipulating the key in the distant office the armature was depressed and released as required, to spell out the message in Morse characters.

After years of use some skilful operators acquired the power of working by ear, which at first was regarded as a matter of curiosity or special interest. It was a long time before ear-receiving became the normal method.

A message can be received by the crudest possible methods. The line may be severed, and one end held above and the other below the tongue, and the pulses, so to say, tasted. Edward Everett Hale has written a very clever story founded on the reception of a Morse message by all of the senses. The printed message appeals to the eye, the sound to the ear, and a message can be felt by placing the fingers on the sounder or even relay magnet; tasting a message has been described already. The reception of a message on chemically treated paper such as used in Bain's chemical telegraph may produce an odor; and Hale tells in his ingenious story of a blind person smelling a message in this way.

The Dangers of Electricity and Conditions for Receiving a Fatal Shock.

The deadly stroke of lightning is not easily produced artificially. It is, if analyzed, the discharge of a very small quantity of electricity of enormous voltage or tension, and probably also of high amperage. The amperage is high because the time of discharge is so very short. There is nothing incompatible between a high amperage and small quantity or few coulombs, and both may refer to the same discharge.

The static electric machines cannot conveniently be made to produce a discharge of this character, as it becomes unmanageable. Yet it would be easy to produce a fatal shock, but hardly with certainty every time.

The development of electric lighting has shown that a fatal shock of much lower voltage than the lightning stroke can be given. It seems as if the amperage had something to do with it, although an intense current rarely goes through the body. Taking its resistance as one thousand ohms, something about which there is nothing definite, it would follow that a single ampere of current will be fatal.

The many fatal shocks received from electric-lighting wires have usually been due to the discharge to earth through the body of a quantity of electricity urged by a potential difference nominally of five hundred or more volts. But it has been found that the character of the current makes a great difference. Dynamos produce currents of different characters. Some currents are almost uniform and in the same direction. These do little harm to the bodily system. Other dynamos produce what is termed a pulsating current, one always in the same direction, but varying in intensity many times every second. Such a current is very severe in its effects.

It will be observed that the voltage of the type of dynamos producing a pulsating current is always incompletely or wrongly stated. The voltage stated is the average, and includes maximum and minimum periods, so that the maximum may be greatly in excess of the registered electromotive force. When the animal system is exposed to a pulsating current, this maximum voltage or electromotive force produces its full effect because a fraction of a second only is required to produce death.

The alternating current is most severe of all. Here the same points of excess of maximum over apparent voltage obtains in still greater force. The probability is at least indicated that the extreme variations of pulsating and alternating currents produce a definitely destructive and shocking effect upon the nervous system.

It is also undoubtedly the nervous shock that kills. Sometimes chemical decomposition of the vital fluids is suggested as a cause of death and injury, but there is little doubt that the shocking and fatal effects of a dynamo discharge are received long before any injurious chemical decomposition results from the trifling current passed.

The general conditions for a fatal or severe shock from an electric-light system using the ground for the return circuit are these: The sufferer standing on the earth touches a bare spot on the wire, or some metallic body in electric connection with the wire. At once he receives a shock of high voltage. If the circuit was in perfect condition no direct current could be received as it would not leave the circuit. The utmost that could be received from a perfect circuit, would be comparatively little; enough in the case of an alternating current to give something of a shock, but hardly enough to kill, and burn the tissues at the points of contact.

Next suppose that the system is imperfect, and that, at a point distant from the person touching the wire, the wire itself is in communication with the ground. Then a new element is introduced. Part of the current goes directly through the person's body, urged by an electromotive force higher or lower as the "ground," or the other point of connection with the earth, is more or less distant, and the shock varies in intensity with such degree of distance and with the consequent higher or lower potential difference.

A single "ground" upon a full metallic-circuit electric light or power system does not interfere to a perceptible extent with its working. But it keeps the whole line in a state ready to discharge a current through any one's body that may touch it. If the point of contact is near the "ground" or point connected with the earth, a discharge of low voltage, and consequently not a severe one, is all that results. But if the "ground" is distant, then the high electromotive force comes into play and the shock may be fatal.

Thus, suppose that a 1,500-volt dynamo is supplying a circuit including three thousand feet of wire with metallic return circuit, and assume the resistance to average the same at all parts. Suppose a ground to be established by any accident five hundred feet from the dynamo as measured on the wire. If then the wire was touched at its farther end, the sufferer would experience a discharge of nearly $\frac{2500}{3000}$ of the total electromotive force or of twelve hundred and fifty volts. If he was but five hundred feet from the "ground," the discharge would be urged with but $\frac{500}{3000}$ of the total, or two hundred and fifty volts.

An electric-light system of high voltage, and of pulsating or alternating current type, on which a ground exists, is comparable to a powder magazine through which people are allowed to walk with lighted candles in their hands. Although but one person suffers, yet his innocence and the utter absence of contributory negligence make the majority of cases doubly sad.

The alternating-current system has the high-tension circuit for supplying only the primaries of its transformers. Sometimes the transformers become injured and are said to leak. This means that the primary and secondary are in metallic or good electric contact. In such a case the secondary circuit, which is the house circuit, participates in all the dangers of a distant "ground."

It follows that "grounds" are to be watched for most vigorously by electric-station superintendents. If the station supplies alternating current, then converter leakages have also to be watched for. It is not alone death that is involved, but fire also. A distant earth connection followed by a second one through a wire or other conducting object in contact with inflammable material may bring about a conflagration.

It is easy to ask for safeguards against these evils. Such provisions must come largely from the engineering department of the electric companies. The misfortune is that the negligence of one concern may do injury to others, and the innocent may suffer in place of the guilty.

APPENDIX.

RECENT IDEAS OF THE NATURE OF ELECTRICITY.

SINCE the first issue of this little book the march of Science has gone steadily onward. New experiments have unveiled new phenomena, and by the study of these phenomena investigators have been led on to further experiments and further discoveries. Next in value to these discoveries and their practical application comes the records of these experiments and their results. It is on the accumulated data of the past that are built the magnificent achievements of the present.

It was in the year 1666 that Newton, as a physicist, enunciated the corpuscular (or emissive) theory of light, in opposition to the wave theory of Kepler, Descartes, Huygens, and Hooke. Newton believed that light consists of an emanation of exceedingly minute particles of matter, projected from the sun and other luminous sources with enormous velocity. These particles he called "corpuscles."

The mathematical and experimental researches of Young and Fresnel, with Arago as collaborator, confirmed, however, the undulatory or wave theory of light and Newton's corpuscles were laid aside in the archives of science.

Franklin's fluid theory of electricity (see p. 26) is akin to Newton's idea of the material or ponderable nature of light. The only difference would be in the fineness of the particles whose motion causes the phenomena.

The brilliant English mathematician and physicist, James Clerk-Maxwell, showed theoretically the identity of light and electricity. This mathematical work received its experimental verification by Heinrich Hertz over a decade after the death of Clerk-Maxwell.

During the past twenty years Sir William Crookes has devoted a great deal of attention to the phenomena of the electric discharge in a vacuum. He has been led to believe that the soft, greenish glow produced by the passage of an electric discharge within a vacuum tube is due to the incandescence of tiny fragments of matter traveling at an incredible speed.

Professor J. J. Thompson has gone still further and has measured the velocity and the mass of these flying particles. It has been further shown that these particles bear a high electrical charge; a stream of them may be deflected by a magnet as if it were an iron rod. Yet more; it has been found that no matter what the origin of the particles, or the material employed, the electrical charge borne by each particle is always the same. It forms a natural unit of electricity.

Professor Thompson has adopted Newton's phraseology and terms these particles "corpuscles." The electrical charge which each corpuscle bears has been termed by Professor Stoney an "electron."

All this leads us to conceive of an electric current as a rush of charged corpuscles, or electrons, along a wire.

It surely does not simplify electricity at the present writing to feel the uncertainty due to this newer corpuscular hypothesis conflicting with the idea of an action in the ether, as mentioned on p. 42.

While continued research will, no doubt, in time remove this uncertainty we must not feel the least apprehension as to the effect of these new views on every-day engineering practice.

The working theories of the dynamo, electro-magnet, electro-chemistry, etc., are too firmly established and highly developed to be seriously troubled by a discussion as to the absolute nature of electricity. There is, however, one important branch of electrical engineering which, the writer believes, will be almost certain to benefit by the solution of this question; it is the art of electric lighting.

The ideal light is like phosphorescence—a glow without heat. The firefly and the glow worm hold this secret, but we have not yet fully solved it. We have no need for the heat which raises the lamp filament to incandescence, or the carbon electrode to a dazzling whiteness. It is light alone which we want.

The white glow of a vacuum tube is the nearest we come to the ideal and our only trouble is to produce this effect with an approach to the high economy which theory indicates as possible.

ELECTRICAL DISCOVERIES AND IMPROVEMENTS OF THE PAST DECADE.

Electric Lighting—Incandescent, Arc, and Vacuum Tube.

In incandescent electric lamps the most prominent novelty is the Nernst lamp. The striking feature of this lamp is that the incandescent body is not in a vacuum but in the air, a glass shade being used merely as a protection.

The filament of the Nernst lamp is not made of carbon but of some refractory materials. Such materials are insulators when cold, but become conductors when heated nearly to redness. The filament has therefore to be heated before the lamp begins to light up. This heating is effected automatically by a heating coil adjoining the filament; this coil is switched out of circuit by a relay when the current begins to flow through the filament.

For the ordinary glass-bulb lamp, Dr. Auer von Welsbach, the inventor of the well-known gas lamp bearing his name, has devised a filament which has combined in it certain of the rare earths and thereby it is made to emit a greater quantity of light per unit of applied energy than the ordinary carbon filament.

In arc lighting a great stride has been made in the production of the enclosed arc lamp. The older, open form of arc lamp would consume a twelve-inch pair of carbons in eight hours. For this reason street arc lamps were provided with two pairs of carbons, so as to furnish light through a winter's night.

Now the carbons in an enclosed arc will burn a hundred hours or more, so it is quickly seen what a saving this is in expense of trimming the lamps.

A new departure in the use of the open arc is the substitution of pencils of magnetite instead of carbon. These magnetite rods last about fifty times longer than carbon and the light is of a brilliant whiteness and from three to four times greater than from carbons using the same power.

Vacuum tube lighting is just commencing to be commercially introduced. Both D. McFarlane Moore and Peter Cooper Hewitt are making installations of this type of lighting.

The Moore electric light is produced in a glass tube one and three-quarter inches in diameter which extends continuously around a room.

This tube is suspended by simple brackets at about the height of the picture moulding. Both ends of the tube extend into a terminal box containing a transformer which is supplied with 110-volt alternating current.

The entire tube is filled with an even, white light, appearing as though it were a long cylinder of densely white vapor. The system at present produces a light twenty-five per cent cheaper than the incandescent lamp, but theory indicates that this efficiency can be much improved. The Cooper Hewitt lamp is not a vacuum tube lamp in the same sense as Moore's, but is rather an arc lamp whose electrodes are of mercury and in which the vacuum permits the arc to become several feet in length.

Its likeness to an arc lamp is markedly shown in the fact that it can only be started either by bringing the terminals into contact and then separating them, or by applying a sufficiently high electro-motive force to drive a current through the vacuum between the terminals.

The light of the mercury arc lamp is peculiar, as it lacks the red rays. This makes it unsuitable for judging color values but, on the other hand, renders it useful for photographic purposes.

X Rays and their Explanation.

It was in 1895, while experimenting with the electrical discharge in vacuum tubes, that Professor W. C. Röntgen discovered the peculiarly penetrating, yet invisible, radiation which he named "X."

These X rays produce fluorescence in certain chemicals and also affect a photographic plate the same as white light. The X rays are invisible to the human eye and therefore either the sensitized plate or a screen coated with a fluorescent material is used to observe their effect.

A most useful property of the X rays is the fact that they readily pass through many substances which are opaque to white light. As various materials are transparent to these rays in varying degree it follows that photographs can be taken and fluorescent shadows can be seen of objects which would be otherwise invisible to us. In this way we can readily examine the bony structure of ourselves and of living animals without the least bodily inconvenience; we may also examine the contents of wooden or cardboard boxes without opening them.

The X rays are produced by the electric discharge in special forms of vacuum tubes, the electrodes being adjusted so as to cause a stream of electrified particles to be projected from the cathode upon a target of aluminum. It is from the point of impact of these particles on the target that the X rays emanate.

It is considered by Professor J. J. Thompson that each of these projected and electrically-charged particles is the center of lines of force radiating in every direction; as these lines of force have a real inertia it follows that when the flying particle strikes the target the whole spherical system of lines of force is stopped with a jolt or pulse which starts at the particle and travels outward with the velocity of light. Experiment and analysis show that this pulse is the seat of intense electric and magnetic forces and it is Professor Thompson's belief that this is what constitutes the X rays.

Telephony.

The principal practical advance in telephone engineering has been in the almost universal adoption, in this country, of the common battery system. In this system the current required for all instruments is supplied from a storage battery at the central station.

The advantages of this arrangement are many. It not only permits of dispensing with a battery and a magneto generator at each subscriber's instrument; but it also reduces the operation of said instrument to the simplest and most obvious movements. At the exchange the substitution of lamp signals has replaced the annunciators and greatly facilitated the work of the operators.

The introduction of the telephone into the guest rooms of hotels has displaced the push button and teleseme systems and enables a guest to at once make his want clearly known at the office. It furthermore puts him in touch with the entire telephone system of the locality in which the hotel is situated.

Entirely mechanical exchange systems are now in practical operation. In these the whole process of connecting a subscriber with a required number is performed by mechanism which most ingeniously provides for notifying the caller if the number wanted is "busy," and disconnects the instruments at the close of a conversation.

The advantages of such mechanical exchanges lie in the elimination of possible delays and misconnections by the operator.

Poulsen's telegraphone is being adapted to the recording of telephonic conversations and to the storing of telephone messages in the absence of the recipient.. The instrument consists of a hardened steel wire wound helically around a brass cylinder, like a screw thread. Sounds are recorded on this steel wire by rotating it past a small electro-magnet whose poles are close to the wire and whose coils are traversed by a telephone current. In this manner a varying magnetism is imparted to the wire as it passes the poles. To reproduce the sounds it is simply necessary to connect the magnet with a telephone receiver and to rotate the wire past the magnet again. The apparatus then becomes a dynamo, generating a speaking current. The impressed variable magnetism is removed by passing the steel wire before the poles of a permanent magnet, thus erasing the record.

Ernest Ruhmer, of Berlin, Germany, has succeeded in transmitting speech over a beam of light ten miles in length. For this work he employs a search light to the circuit of which is connected a carbon transmitter and a battery. This transmitter superimposes electric sound waves on the arc lamp circuit. The projected beam of light is received by a parabolic reflector which focuses it upon a selenium cell in circuit with a battery and a pair of very sensitive telephone receivers. Selenium has the peculiar property of varying in resistance when subjected to a varying illumination; so, in the above apparatus the slight variation which a person's speech produces in the light of the projector causes changes in the resistance of the selenium cell sufficient to vary the local current and reproduce the speech in the receivers.

Through the experimental and mathematical researches of Dr. M. I. Pupin, of Columbia University, in electrical resonance and induction, it is now possible to improve the speed of signaling through ocean cables and to converse by telephone through fifteen miles of cable as clearly and distinctly as through a three-mile length without his invention. Dr. Pupin's improvement consists in connecting into the cable, at certain points, self-induction coils; these neutralize the capacity of the cable, and give an effect equivalent to an open-air pole line.

Wireless Telegraphy.

The transmitting apparatus, in most systems of wireless telegraphy, consists of a powerful induction coil. In its primary circuit is the source of electric current and a signaling key. The secondary circuit is connected to two adjacent metal spheres, the space between which constitutes a spark gap through which the current in the secondary coil is discharged. Furthermore, one of these spheres is connected to the ground, the other to an elevated vertical wire.

From the vertical wire of such an apparatus issue into space electric waves which take their rise from the discharges across the spark gap of the induction coil.

To detect and utilize the signals formed by these radiating electric waves a receiving apparatus is established, which consists of an elevated vertical wire which is the counterpart of that in the transmitting station. This wire is connected to the ground through the primary of an induction coil.

In the secondary circuit of this coil is placed the coherer, which is the prime factor of wireless systems.

The usual form of coherer comprises a small glass tube about one and one-half inches long and one-twelfth inch internal diameter. The terminals of the circuit end in the tube with two snugly-fitting plugs of silver, each two-tenths of an inch in length. These silver plugs have a space of one-thirtieth inch between their ends and in this space some metal filings are loosely placed. When electric waves surge across this apparatus in a receiving station these loose filings *cohere* and conduct a weak battery current much more readily than before. When the waves have ceased, a gentle tap on the tube is sufficient to cause the filings to *decohere,* thus placing the apparatus in a receptive state again.

In practice, at the moment of cohering, the local circuit is caused to operate a tapper like the hammer of an electric bell. Thus the decohering is accomplished automatically.

The most noted achievement of wireless telegraphy was on Thursday, December 12, 1901, when Marconi and his assistant, Mr. Kemp, stationed at Cape Race, Newfoundland, received the first transatlantic signals from Poldhu, Cornwall, England. The distance apart of the stations was about two thousand miles, and the curvature of the earth is such as to form between the stations a hill one hundred and ten miles in height.

Electric Railway Developments.

Since 1887 the trolley car has been rapidly extended throughout the country, displacing horse, mule, and cable cars.

With this progress has grown the desire to apply electric power to the propulsion of trains.

This was at first accomplished by the use of electric locomotives which simply took the place of steam locomotives.

Electric power is, however, capable of much easier subdivision into small units of high efficiency than is steam power. This fact lies at the foundation of the multiple unit system of electric traction, the invention of Mr. Frank J. Sprague.

In this system each car is provided with motors, just as is an ordinary trolley car; but, instead of the controller being placed on the platform and operated by hand, it is located beneath the car or under the seats and is operated by electricity or compressed air from a master-switch on the platform.

Now when a train is made up, each car gets its own current from the third rail by means of contact shoes, but, by means of coupling cables, called "jumpers," the master-switch circuit extends throughout the train, as does also the controlling pipe of the air brake system. By these means the train may be entirely managed from either end, or at any intermediate point, if need be.

The great beauty of the multiple unit system lies in the power being available in proportion to the work to be done, and also in the division of the motors into units of comparatively small weight. It is manifest that no matter how long or how short a train may be, it will always have motors of sufficient power to run it, and that their weight will be evenly distributed instead of being concentrated in a heavy locomotive.

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